27992

No. ~~B3665~~ DEPARTMENT OF

q557 X

LIBRARY OF v.13³

University of Illinois.

cop. 2

Books are not to be taken from the Library Room.

THIRTEENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1891-'92

BY

J. W. POWELL
DIRECTOR

IN THREE PARTS

PART III—IRRIGATION

WASHINGTON
GOVERNMENT PRINTING OFFICE
1893

CONTENTS OF PART III.

WATER SUPPLY FOR IRRIGATION, BY F. H. NEWELL.

Page.
Introduction ... 7
  Preceding reports ... 7
  Area irrigated ... 8
  Area irrigable ... 9
  Size of streams ... 10
  Relative run-off ... 13
  Fluctuations of rivers and lakes ... 15
  Nonperiodic oscillations ... 18
  Variations and precipitation ... 25
  Subsurface waters ... 28
  Cost and value of water supply ... 30
  Principal drainage basins ... 31
Missouri river basin ... 34
  Location and area ... 34
  Elevation and topography ... 35
  Land classification ... 35
  Extent of irrigation ... 36
  Water measurements ... 38
  Precipitation ... 39
  Gallatin river ... 41
  Madison river ... 46
  Jefferson river ... 49
  Missouri valley ... 53
  Prickley Pear valley ... 54
  Dearborn and Sun rivers ... 55
  Chestnut valley and Smith river ... 57
  Teton and Marias rivers ... 59
  Judith and Musselshell rivers ... 60
  Milk river ... 62
Yellowstone river basin ... 63
  Location ... 63
  Area and topography ... 64
  Area irrigated ... 65
  Water measurements ... 65
  Precipitation ... 67
  Yellowstone river, above Bighorn ... 68
  Bighorn river ... 69
  Tongue river ... 70
  Powder river ... 71
  Lower Yellowstone river ... 72

27992

Page.
Platte river basin 73
  Location and area 73
  Elevation and topography 74
  Land classification 75
  Extent of irrigation 75
  Water measurements 76
  Precipitation 76
  Upper North Platte 78
  Laramie river 79
  Lower North Platte 81
  South Platte, above Denver 82
  Cache la Poudre and other creeks 86
  South Platte, below Greeley 90
Tables of mean monthly and annual discharge 92

AMERICAN IRRIGATION ENGINEERING, BY HERBERT M. WILSON.

Preface 109
Introduction 113

CHAPTER I.

Economical and financial aspects of irrigatian 121
Alkali and drainage 127
Silt and sedimentation 130

CHAPTER II.

History and legislation 133
Legislation and administration 139

CHAPTER III.

Hydrography, evaporation, and seepage 152
Duty of water 155
Alignment, cross-section, and slope 158

CHAPTER IV.

Classes of works 162
Perennial canals 163
Kings river canals 164
Calloway canal 168
Del Norte canal 171
Arizona canal 175
Highline canal 179
Wyoming Development Company's canal 181
Kraft Irrigation district canal 184
Pecos valley canals 187
Central Irrigation district canal 191
Bear river canal 194
Idaho Mining and Irrigation Company's canal 198
Turlock canal 203
Folsom canals 210
Other important canals 214

CHAPTER V.

Page
Headworks 218
Weirs 219
    Crib 221
    Open 227
    Composite 230
    Masonry 230
Diversion dams 234
Regulators 238
Escapes 244
Falls and rapids 249
Drainage works, flumes, siphons, etc 256

CHAPTER VI.

Distribution and measurement of water 268
Application of water 274
Maintenance and supervision 281

CHAPTER VII.

Water storage 284
San Diego Flume Company 286
Merced reservoir 290
Long valley reservoir 294
Walnut Grove reservoir 297
Castlewood reservoir 302
Bear valley reservoir 305
Sweetwater reservoir 310
Other reservoir projects 314
Construction of dams 321

CHAPTER VIII.

Subsurface sources of supply 326
Pumping 332
Subirrigation 338
Tools and machinery 342
Authors' list 346

ENGINEERING RESULTS OF IRRIGATION SURVEY, BY HERBERT M. WILSON.

Introduction 357
Arkansas basin, Colorado 362
    Engineering work 364
    Twin lakes reservoir 365
    Twin lakes dam 367
Sun river system, Montana 371
    Reservoirs 374
    Canal lines 383
    Areas of land reclaimable 385
    Revenue 386
Truckee and Carson river systems, Nevada 387
  Truckee river basin 389
    Donner lake reservoir 389
    Independence lake reservoir 391
    Webber lake reservoir 392
    Lower Truckee canals 393

Page.
Truckee and Carson river systems, Nevada—Continued.
  Carson River basin 394
    Long valley reservoir 394
    Hope valley reservoir 395
California division 398
  High sierra reservoirs 398
    Results of surveys 400
    Bear valley reservoir 401
    Kennedys meadow reservoir 401
    Kennedys lake reservoir 402
    Lake Eleanor reservoir 402
    Tuolumne meadow reservoir 403
    Lake Tenaiya reservoir 404
    Little Yosemite reservoir 404
  Clear lake survey 405
El Paso reservoir 410
    Surveys 412
    Flood water storage 414
    Upper site for dam 415
    Design for dam 415
    Estimated cost 417
    Removal of the Southern Pacific R. R 419
    Removal of the Santa Fe R. R 420
Pocatello canal, Idaho 422
    Structures 426

REPORT UPON THE CONSTRUCTION OF TOPOGRAPHIC MAPS AND THE SELECTION AND SURVEY OF RESERVOIR SITES IN THE HYDROGRAPHIC BASIN OF THE ARKANSAS RIVER, COLORADO, BY A. H. THOMPSON.

Topographic maps 431
Topography 433
Reservoir sites 435

REPORT UPON THE LOCATION AND SURVEY OF RESERVOIR SITES DURING THE FISCAL YEAR ENDING JUNE 30, 1892, BY A. H. THOMPSON.

Introduction 451
Utah-Idaho 452
    Reservoir site No. 1, Bear lake 452
Utah 458
    Reservoir site No. 2, Silver lake, Salt Lake county 458
    Reservoir site No. 3, Twin lakes, Salt Lake county 460
    Reservoir site No. 4, Marys lake, Salt Lake county 460
    Reservoir site No. 5, on Sevier river, Millard county 461
    Reservoir site No. 6, on Sanpitch river, Sanpete county 463
    Reservoir site No. 7, on Sevier river, Piute county 465
    Reservoir site No. 8, on East fork of Sevier river, Piute county 466
    Reservoir site No. 9, on Otter creek, Piute county 468
    Reservoir site No. 10, on East fork of Sevier river, Garfield county 470
    Reservoir site No. 11, on East fork of Sevier river, Garfield county 473
    Reservoir site No. 12, Panquitch lake, Iron county 475
    Reservoir site No. 18, at Blue spring, Iron county 477

ILLUSTRATIONS.

Page.
Plate CVIII. Map of the drainage basin of the Missouri river in Montana.... 44
CIX. Map of the drainage basin of the Yellowstone river............ 64
CX. Map of the drainage basin of the Platte river.................. 74
CXI. Pueblo canal. Verde valley, Arizona.......................... 132
CXII. Del Norte canal. View of rapid.............................. 172
CXIII. Arizona canal system and plan of headworks................. 174
CXIV. Arizona canal. View of Big fall............................. 176
CXV. Pecos canal.. 190
CXVI. Bear river canal in canyon.................................. 196
CXVII. View of Idaho canal during construction.................... 198
CXVIII. Phyllis canal pipeline.................................... 200
CXIX. Phyllis canal rapid... 202
CXX. Turlock canal. View of main line............................. 208
CXXI. View of pile weir across Platte river....................... 220
CXXII. Arizona canal. View of second weir......................... 222
CXXIII. Bear river canal. View of weir during construction........ 226
CXXIV. Calloway canal. View of weir and canal regulation head..... 228
CXXV. San Diego flume. View of weir............................... 230
CXXVI. Folsom canal. Plan, cross section, and elevation of weir and headworks... 232
CXXVII. Pecos canal. View of dam.................................. 234
CXXVIII. Del Norte canal. View of regulator from inside........... 336
CXXIX. Arizona canal. View of regulator gates..................... 238
CXXX. Bear river canal. Elevation and cross sections of weir and regulator... 240
CXXXI. Central Irrigation District canal. Plan and elevation of regulator... 242
CXXXII. Folsom canal. View of weir and regulator.................. 244
CXXXIII. Folsom canal. Plan, cross section and elevation of regulator... 246
CXXXIV. Arizona canal. View of falls............................. 250
CXXXV. Highline canal. View of bench flume........................ 258
CXXXVI. San Diego flume. View on bench............................ 260
CXXXVII. San Diego flume. Trestle across Los Coches creek......... 262
CXXXVIII. Pecos canal. View of flume.............................. 264
CXXXIX. Orchard irrigation by sidewise soakage from ditches........ 278
CXL. San Diego flume. View of tunnel and approach.................. 286
CXLI. View of Castlewood dam...................................... 302
CXLII. Sweetwater dam. Plan, cross section, and details of wasteway. 310
CXLIII. View of Sweetwater dam.................................... 312
CXLIV. San Mateo dam. Plan, cross section, and outlet sluices..... 320
CXLV. View of San Mateo dam....................................... 322
CXLVI. San Francisco Bridge Company's excavator................... 344

Page.
PLATE CXLVII. Topographic map, Arkansas basin........................In pocket.
CXLVIII. Cottonwood reservoir site 363
CXLIX. Clear creek reservoir site 364
CL. Monument reservoir site 365
CLI. Leadville reservoir site 366
CLII. Sugarloaf reservoir site 367
CLIII. Tennessee park reservoir site 368
CLIV. Hayden reservoir site 369
CLV. Pring reservoir site 370
CLVI. Twin lakes reservoir site 371
CLVII. Sun river system 372
CLVIII. Method of survey ....In pocket.
CLIX. Sun river reservoir site No. 1 374
CLX. Sun river reservoir site No. 2 375
CLXI. Sun river reservoir site No. 3 376
CLXII. Sun river reservoir site No. 4 377
CLXIII. Sun river reservoir site No. 5 378
CLXIV. Sun river reservoir site No. 6 379
CLXV. Sun river reservoir site No. 7 380
CLXVI. Sun river reservoir site No. 8 381
CLXVII. Sun river reservoir site No. 9 382
CLXVIII. Benton lake reservoir site 383
CLXIX. Willow creek and Augusta canal 384
CLXX. Donner lake reservoir site 390
CLXXI. Independence lake reservoir site 391
CLXXII. Webber lake reservoir site 392
CLXXIII. Long valley reservoir site 394
CLXXIV. Hope valley reservoir site 396
CLXXV. Kennedys meadow and Kennedys lake reservoir sites 400
CLXXVI. Lake Eleanor reservoir site 402
CLXXVII. Tuolumne meadow reservoir site 403
CLXXVIII. Lake Tenaiya and Bear valley reservoir sites 404
CLXXIX. Little Yosemite reservoir site 405
CLXXX. Clear lake 406
CLXXXI. El Paso reservoir site 410
CLXXXII. Pocatello canal head; site of headworks 422
CLXXXIII. Reservoir site No. 1, Bear lake, Utah-Idaho 452
CLXXXIV. Reservoir site No. 6, on Sanpitch River, Sanpete County, Utah 462
FIG. 42. Diagram of maximum, minimum, and mean discharges of western rivers 11
43. Diagram of discharges of large rivers of the United States 12
44. Diagram showing relative size of drainage basins and depth of run-off. 13
45. Diagram of periodic oscillations of water level 17
46. Diagram of nonperiodic oscillations of various rivers and lakes 21
47. Diagram of nonperiodic oscillations of Colorado, King, and San Joaquin rivers ... 22
48. Diagram showing comparison of nonperiodic oscillations of the Great Lakes with Great Salt lake ... 22
49. Diagram of nonperiodic oscillations of the Great Lakes 23
50. Diagram of the distribution of the mean monthly precipitation at sixteen stations in western United States ... 27
51. Index map of large drainage basins 32
52. Diagram of mean monthly rainfall at four stations in the Missouri basin 40

Page.
Fig. 53. Diagram of daily discharge of West Gallatin river below Spanish creek, Montana 43
54. Diagram of daily discharge of Madison river near Red Bluff, Montana. 48
55. Diagram of daily discharge of Missouri river at Craig, Montana 58
56. Diagram of daily discharge of Yellowstone river near Horr, Montana. 66
57. Diagram of daily fluctuations of North Platte river, Wyoming 83
58. Diagram of daily discharge of South Platte river, near Deansbury, Colorado 84
59. Diagram of daily discharge of South Platte river at Denver, Colorado. 85
60. Diagram of daily discharge of Clear creek, Colorado 86
61. Diagram of daily discharge of North Boulder creek, Colorado 87
62. Diagram of daily discharge of St. Vrain creek, Colorado 88
63. Diagram of daily discharge of Big Thompson creek, Colorado 89
64. Plan and profile of Pueblo canal, Verde valley, Arizonac 134
65. Ancient dam, San Luis Obispo county, California 136
66. Cross sections of canal banks, Calloway, Idaho, and Turlock canals .. 160
67. Calloway canal system and plan of headworks 170
68. Del Norte canal system and plan of headworks 173
69. Del Norte canal. Plan of main bifurcation 174
70. Wyoming Development Company's canal system, A, and cross section of weir, B 182
71. Kraft Irrigation District canal system 184
72. Kraft Irrigation District. Plan of headworks 185
73. Kraft Irrigation District. Excavation for fall 187
74. Pecos canal system 189
75. Bear river canal system 195
76. Bear river canal. Cross section of hillside work 197
77. Bear river canal. Cross sections of Corinne branch canal 198
78. Idaho canal system and plan of headworks 199
79. Turlock canal system 204
80. Turlock canal. Plan of headworks 205
81. Turlock canal. View of sidehill work 206
82. Turlock canal. Cross section of sidehill work 207
83. Turlock canal tunnel 208
84. Folsom canal system 211
85. Arizona canal. Cross section of first weir 221
86. Arizona canal. Cross section of second weir 222
87. Highline canal. View of weir 225
88. Kraft irrigation district canal. Cross section of weir 226
89. Calloway canal. Cross section of weir 228
90. Monte Vista canal weir 229
91. San Diego flume. Plan, elevation, and cross section of weir 231
92. Turlock canal. Cross section of weir 232
93. Folsom canal weir. Hydraulic jack 234
94. Idaho canal. Cross section of dam 235
95. Idaho canal. Plan and elevation of headworks 236
96. Pecos canal. Plan of headworks 237
97. Pecos canal. Cross section of dam 238
98. Del Norte canal. Elevation and cross section of regulator gates 240
99. Idaho canal. View of rolling regulator gate 244
100. Arizona canal. View of escape 246
101. Idaho canal. Elevation and cross section of escape 248
102. Folsom canal. Cross section and elevation of sand gates 249
103. Calloway canal. View of fall 251

Page.
FIG. 104. Arizona canal cross-cut. Cross section of fall 252
105. Fresno canal. Plan and cross section of fall 253
106. Bear river canal. Plan and cross section of fall on Corinne branch. 254
107. Turlock canal. Cross section of fall 254
108. Uncompahgre canal. Cross section of fall 255
109. Grand river canal. Plan and elevation of big drop 255
110. Turlock canal. Plan and cross section of Dry creek drainage dam... 258
111. Types of flumes and trestles 259
112. Idaho canal. Cross section of low flume 260
113. San Diego flume. Cross section 261
114. Bear river canal. View of iron flume over Malade river 262
115. Bear river canal. Elevation and cross section of iron flume on Corinne branch 263
116. Arapaho canal. Cross section of Siphon head 264
117. Del Norte canal. Cross section and end elevation of culvert 265
118. Central Irrigation District canal. Elevation and cross section of Stony creek culvert 267
119. Water distribution, Riverside, California 269
120. Laybourn iron flume. Perspective and cross sections 270
121. Calloway canal. View of distributary head 271
122. Foote's measuring flume, A. Plan of water divisor, B 273
123. Irrigation by flooding 275
124. Application of water by flooding 276
125. Application of water by check system 277
126. Application of water by block system 278
127. Application of water by furrows 279
128. Merced reservoir system 291
129. Honey lake valley reservoir system 294
130. Honey lake dam, cross section 296
131. View of Walnut Grove dam during construction 298
132. Walnut Grove dam. Cross section and elevation 299
133. Castlewood dam. Plan, elevation, and cross section 303
134. Bear valley reservoir system 305
135. Old Bear valley dam. Cross section 307
136. Old Bear valley dam. Plan and elevation 307
137. New Bear valley dam. Plan and cross section 308
138. Buchanan reservoir system 314
139. Citizens' Water Company dam. Cross section 318
140. Citizens' Water Company dam. Elevation 319
141. Bowman dam. Plan and cross section 323
142. Fordyce dam. Plan and cross section 324
143. San Fernando dam 332
144. Water wheel 334
145. Discharge flume from steam pump, Tucson, Arizona 337
146. Colorado wooden pipe 339
147. Alessandro hydrant 341
148. Buck scraper 343
149. Fresno scraper 344
149*b*. New Era excavator 345
150. Reservoir site No. 2, Silver lake, Salt Lake county, Utah 459
151. Reservoir site No. 3, Twin lakes, Salt Lake county, Utah 460
152. Reservoir site No. 4, Marys lake, Salt Lake county, Utah 461
153. Reservoir site No. 5, on Sevier river, Millard county, Utah 462
154. Reservoir site No. 7, on Sevier river, Piute county, Utah 466

Page.
FIG. 155. Reservoir site No. 8, on East fork of Sevier river, Piute county, Utah ... 467
156. Reservoir site No. 9, on Otter creek, Piute county, Utah ... 470
157. Reservoir site No. 10, on East fork of Sevier river, Garfield county, Utah ... 471
158. Reservoir site No. 11, on East fork of Sevier river, Garfield county, Utah ... 474
159. Reservoir site No. 12, Panquitch lake, Iron county, Utah ... 475
160. Reservoir site No. 13, at Blue spring, Iron county, Utah ... 477

DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY.

WATER SUPPLY FOR IRRIGATION.

By FREDERICK HAYNES NEWELL.

CONTENTS.

Page.
Introduction 7
  Preceding reports 7
  Area irrigated 8
  Area irrigable 9
  Size of streams 10
  Relative run-off 13
  Fluctuations of rivers and lakes 15
  Nonperiodic oscillations 18
  Variations in precipitation 25
  Subsurface waters 28
  Cost and value of water supply 30
  Principal drainage basins 31
Missouri river basin 34
  Location and area 34
  Elevation and topography 35
  Land classification 35
  Extent of irrigation 36
  Water measurements 38
  Precipitation 39
  Gallatin river 41
  Madison river 46
  Jefferson river 49
  Missouri valley 53
  Prickly Pear valley 54
  Dearborn and Sun rivers 55
  Chestnut valley and Smith river 57
  Teton and Marias rivers 59
  Judith and Musselshell rivers 60
  Milk river 62
Yellowstone river basin 63
  Location 63
  Area and topography 64
  Area irrigated 65
  Water measurements 65
  Precipitation 67
  Yellowstone river, above Bighorn 68
  Bighorn river 69
  Tongue river 70
  Powder river 71
  Lower Yellowstone river 72
Platte river basin 73
  Location and area 73
  Elevation and topography 74

Page
Platte river basin—Continued.
Land classification 75
Extent of irrigation 75
Water measurements 76
Precipitation 76
Upper North Platte 78
Laramie river 79
Lower North Platte 81
South Platte, above Denver 82
Cache la Poudre and other creeks 86
South Platte, below Greeley 90
Tables of mean monthly and annual discharge 91

ILLUSTRATIONS.

Page.

PLATE CVIII. Map of the drainage basin of the Missouri river in Montana... 34

CIX. Map of the drainage basin of the Yellowstone river........... 64

CX. Map of the drainage basin of the Platte river................ 74

FIG. 42. Diagram of maximum, minimum, and mean discharges of western rivers.......... 11

43. Diagram of discharges of large rivers of the United States....... 12

44. Diagram showing relative size of drainage basins and depth of run-off.......... 13

45. Diagram of periodic oscillations of water level................ 17

46. Diagram of nonperiodic oscillations of various rivers and lakes.. 21

47. Diagram of nonperiodic oscillations of Colorado, King, and San Joaquin rivers.......... 22

48. Diagram showing comparison of nonperiodic oscillations of the Great Lakes with Great Salt lake.......... 22

49. Diagram of nonperiodic oscillations of the Great Lakes.......... 23

50. Diagram of the distribution of the mean monthly precipitation at sixteen stations in western United States.......... 27

51. Index map of large drainage basins.......... 32

52. Diagram of mean monthly rainfall at four stations in the Missouri basin.......... 40

53. Diagram of daily discharge of West Gallatin river below Spanish creek, Montana.......... 43

54. Diagram of daily discharge of Madison river near Red Bluff, Montana.......... 48

55. Diagram of daily discharge of Missouri river at Craig, Montana.. 58

56. Diagram of daily discharge of Yellowstone river near Horr, Montana.......... 66

57. Diagram of daily fluctuations of North Platte river, Wyoming.... 83

58. Diagram of daily discharge of South Platte river near Deansbury, Colorado.......... 84

59. Diagram of daily discharge of South Platte river at Denver, Colorado.......... 85

60. Diagram of daily discharge of Clear creek, Colorado.......... 86

61. Diagram of daily discharge of North Boulder creek, Colorado.... 87

62. Diagram of daily discharge of St. Vrain creek, Colorado.......... 88

63. Diagram of daily discharge of Big Thompson creek, Colorado.... 89

WATER SUPPLY FOR IRRIGATION.

By F. H. Newell.

INTRODUCTION.

This report is the fourth in a series, each one of which relates to a certain extent to the hydrography of the arid regions, viz, to facts concerning the quantity and distribution of water. Since these papers give the results obtained at various stages of progress, the one which is issued last must necessarily refer to data previously published, and perhaps repeat or modify some of the former statements. Before entering upon the subject-matter of this paper reference should be made to the preceding discussions, which are contained, respectively, in the first, second, and third annual reports of the Irrigation Survey, these being also known as parts II of the Tenth, Eleventh, and Twelfth Annual Reports of the U. S. Geological Survey.

PRECEDING REPORTS.

In the first annual report of the Irrigation Survey, on page 19, a description is given of the organization of this branch of the work, and on pages 78 to 90 Capt. C. E. Dutton reports upon the methods of the investigation and briefly describes a few of the results then obtained. In the second report, on pages 1 to 110, are given more detailed descriptions of methods and instruments, and also of the localities at which stream measurements have been made, the character of each drainage basin being briefly noted. The results of stream measurements are also shown in tabular form convenient for reference.

The third annual report of the Irrigation Survey continues the discussion of the subject of water supply or hydrography of the arid regions, and gives the results of measurements and investigations obtained during the fiscal year ending June 30, 1891. General descriptions are also given of the topographic and other features of some of the drainage basins, the discussion of the Rio Grande and Gila basins being particularly detailed. The present report, continuing in a line similar to that pursued in the cases of the drainage basins just mentioned, describes with equal fullness other of the more important basins, and brings together all available information bearing upon the water supply.

AREA IRRIGATED.

The total area upon which crops were raised by irrigation was, according to the results obtained by the Eleventh Census, 3,631,381 acres, or 5,674.03 square miles. This applies to the year ending May 31, 1890, the census being taken during the following June. Comparing this area with the total land surface west of the one hundredth meridian, it is found to be approximately only four-tenths of 1 per cent. In other words, for every acre from which crops were obtained by irrigation there were nearly 250 acres of land most of which was not utilized in any way except for pasturage.

The area of the land surface of the United States west of the one hundredth meridian and between it and the Pacific ocean is 1,371,960 square miles, not including thirty-six counties of western Oregon and Washington. Within this great extent of country are nearly all possible combinations of soil and climate, ranging from the smooth, almost barren, plains with scanty vegetation to the high rough mountains, the peaks covered throughout the year with snow and the slopes clothed with thick forests. In a broad way four great classes of land may be distinguished, according to the amount of moisture received or the water supply available, as shown principally by the character of the vegetation.

The following table gives approximately the amount of land embraced in each of these great classes:

	Square miles.
Desert	100, 000
Pasture	961, 960
Firewood	180, 000
Timber	130, 000
Total	1, 371, 960

The desert land is that within which the water supply is so small that the cattle can not obtain sufficient for drinking purposes, and the vegetation is too scanty or uncertain to be of value for pasturage. The soil is often rich, and with water would produce large crops.

The second class embraces all the Great Plain region, which, owing to the prevailing aridity, is useful mainly as pasturage. The localities at which agriculture is possible are relatively of insignificant size, although of great importance in a grazing country. This class also includes the valley lands within the Rocky Mountain region and the rolling hills, on which native grasses grow.

The land containing firewood is mainly that fringing the timbered areas, being intermediate in character between the pasture land and the high rough forested slopes or plateaus. It includes also the precipitous hillsides found at an elevation too low to receive a large or constant supply of moisture, which in general falls upon the more heavily timbered areas.

The fourth class embraces the forested areas upon the high mountains, where the conditions are such that trees have been able to attain a size suitable for timber. A large part of this area has been burned over at different times, destroying timber whose value to the country can scarcely be estimated, and a relatively small number of the trees have been cut for lumber, to supply the growing needs of the settlers. The existence of this timber, however, indicates a condition of climate and soil widely different from that prevailing over the plains or pasture lands.

The irrigated and irrigable lands are mainly included within those divisions which in their natural state are considered as desert or pasture lands. In a broad way it may be said that fully nine-tenths of this area is covered with a fertile arable soil, which only lacks sufficient moisture in order to be of great value for agriculture. Out of this total of, in round numbers, over 610,000,000 acres there have been, according to the census, 3,631,381 acres, or less than six-tenths of one per cent, provided with a water supply sufficient to enable crops to be raised.

AREA IRRIGABLE.

The proportion of this desert or pasture land which can be brought under irrigation in future is dependent upon the thoroughness with which the water supply is utilized. It is obvious at the outset, however, that this proportion must be small, probably under 3 per cent, but its exact amount can be determined only when the available waters of the region have been accurately measured. This simple fact, namely, that the area irrigable is governed by the amount of water flowing in the streams, at various times of the year, is often overlooked or forgotten in popular discussions of the subject.

The greater part of the available water supply comes from the high mountains with precipitous slopes, a less quantity being discharged from foothills, and a still smaller quantity, irregular in time of occurrence, from valleys or plains. The results of measurements have shown that the average amount of water, taking one year with another, is seldom greater than 1 cubic foot per second or second-foot per square mile of elevated and steep catchment area. The total catchment of this character within the area under discussion has been ascertained to be 360,000 square miles. This includes the greater part of the areas designated as being covered by timber and firewood. From the remaining land, namely, the pasture and desert, there is very little water available for irrigation. Although there is a large amount of water falling upon these tracts, yet the conditions are such that streams valuable to agriculture are seldom formed, for the greater part of the moisture either sinks into the ground and is subsequently lost by evaporation, or, when coming in heavy showers, flows off in the streams whose beds are nearly or quite dry for the rest of the year, and thus is plentiful only at times when there is no need of irrigation.

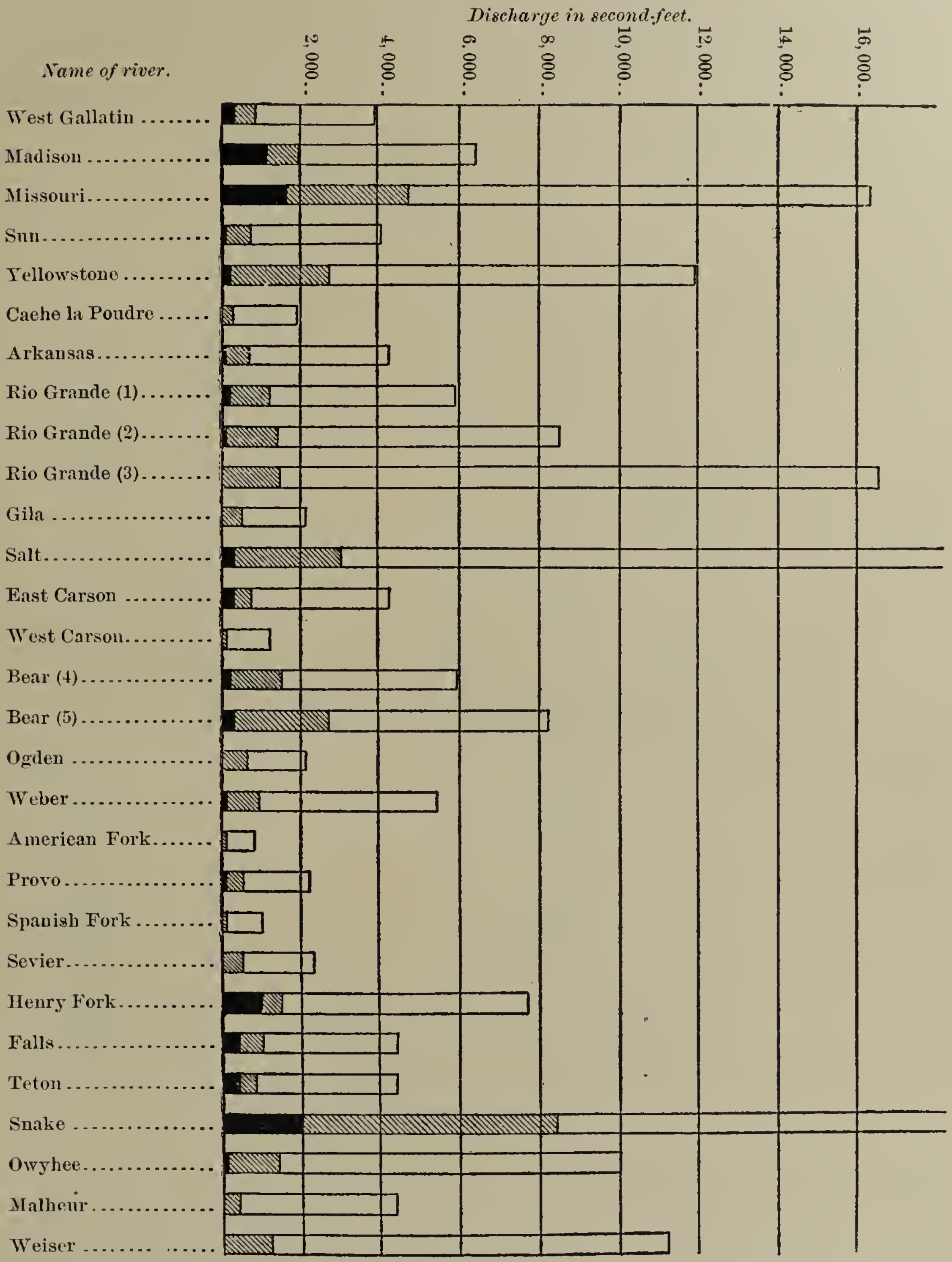
Assuming that there is an average annual discharge of one second-foot from each of the 360,000 square miles, the total amount of water available for the supply of the 610,000,000 acres of pasture and desert lands above-mentioned is 360,000 second-feet. Much of this water, however, escapes into large rivers which have cut their channels so far beneath the general level of the arable lands that the waters can not be diverted, and therefore they must be considered as lost to agriculture. This is notably the case with many rivers in the drainage basin of the Colorado river, also to a great degree in that of the Columbia. The total amount available for irrigation is therefore to be diminished by the quantity lost in this manner.

The amount of water which can be saved by storage systems in the undulating and hilly country, or utilized by the conservation of water from springs or flowing wells, is a quantity even more uncertain than that flowing from the mountains, for in this case there are few general facts of broad application. It may be assumed, however, that this amount will not exceed the quantity lost in deep drainage channels, such as those of the Colorado and Columbia systems. Taking, therefore, the whole amount of water available in the arid region as 360,000 second-feet, the area of land which can be irrigated can be approximately ascertained by assuming a standard duty of water. If, for example, 1 second-foot flowing throughout the year will irrigate 100 acres, then the total irrigable area is approximately 36,000,000 acres, or about ten times that upon which crops were raised by irrigation in the census year. With an average water duty of 150 acres to the second-foot, the area irrigable will be 54,000,000 acres, and so on, according to the duty of water assumed.

SIZE OF STREAMS.

The relative amount of water discharged by various rivers of importance to irrigation is shown by the diagram, Fig. 42, which gives at a glance the size of these streams at times of high and low water, and also the average for one or two years or more. From this diagram may be inferred the acreage which possibly can be irrigated by each of these streams by assuming a standard duty of water. In this figure the names of the rivers are given in the space to the left, and to the right of each of these is a bar whose length indicates the quantity of water in the stream. The vertical lines give the quantity in cubic feet per second. For example, in the case of the first stream, the West Gallatin, the bar almost reaches the 4,000 line, indicating that the discharge fell under this amount, while in the case of the Missouri it was over 16,000. The black portion of the bar, by its length, indicates the minimum discharge of the stream for the time during which measurements were made, while the shaded portion, including the black, shows the average discharge. The total length of the bar, including the black, cross-hatched, and unshaded portions, indicates the maximum discharge.

In the case of two of the streams shown in this diagram, the maximum discharge exceeds the amount which can be shown on the sheet, that of the Salt being 300,000 second-feet, requiring to show it a diagram containing seventeen times the space allowed on Fig. 42, and in the case of the Snake 50,000 second-feet, or about three times the allotted space. In order to make a comparison between the streams of the arid region and some well-known rivers in the east, a second diagram,



(1) at Del Norte, Colo.; (2) at Embudo, N. Mex.; (3) at El Paso, Tex.; (4) at Battle Creek, Idaho; (5) at Collinston, Utah.

FIG. 42.—Diagram of maximum, minimum, and mean discharges of western rivers.

Fig. 43, is introduced, showing similar facts, the scale, however, being much smaller. The relative change in scale can be seen by comparing the small space opposite the words "Upper Missouri" in Fig. 43 with the length of the line representing the same quantity in Fig. 42, this latter being the third line or bar from the top. In Fig. 43 the flood discharges of the Snake river at Idaho Falls, Idaho, and of the Salt river above Phœnix, Arizona, are shown in their relative proportions, the mean discharges being, however, scarcely perceptible on this diagram. The computations of discharge of Sacramento river apply to the total outflow as determined by the state engineer of California. The remaining streams shown on Fig. 43, those in the eastern part of the country, were measured by officers of the Corps of Engineers, U. S. Army, except in the case of the Potomac, where gaugings were made by this Survey. The quantities shown on the diagram apply to the total discharge. The amount of water in the Mississippi at a point below the mouth of the Ohio would be represented by combining the three lines or bars at the bottom of the diagram. These three sets of values there shown, namely, for the Missouri, Upper Mississippi, and Ohio, represent strictly the discharges for the year 1882 only.

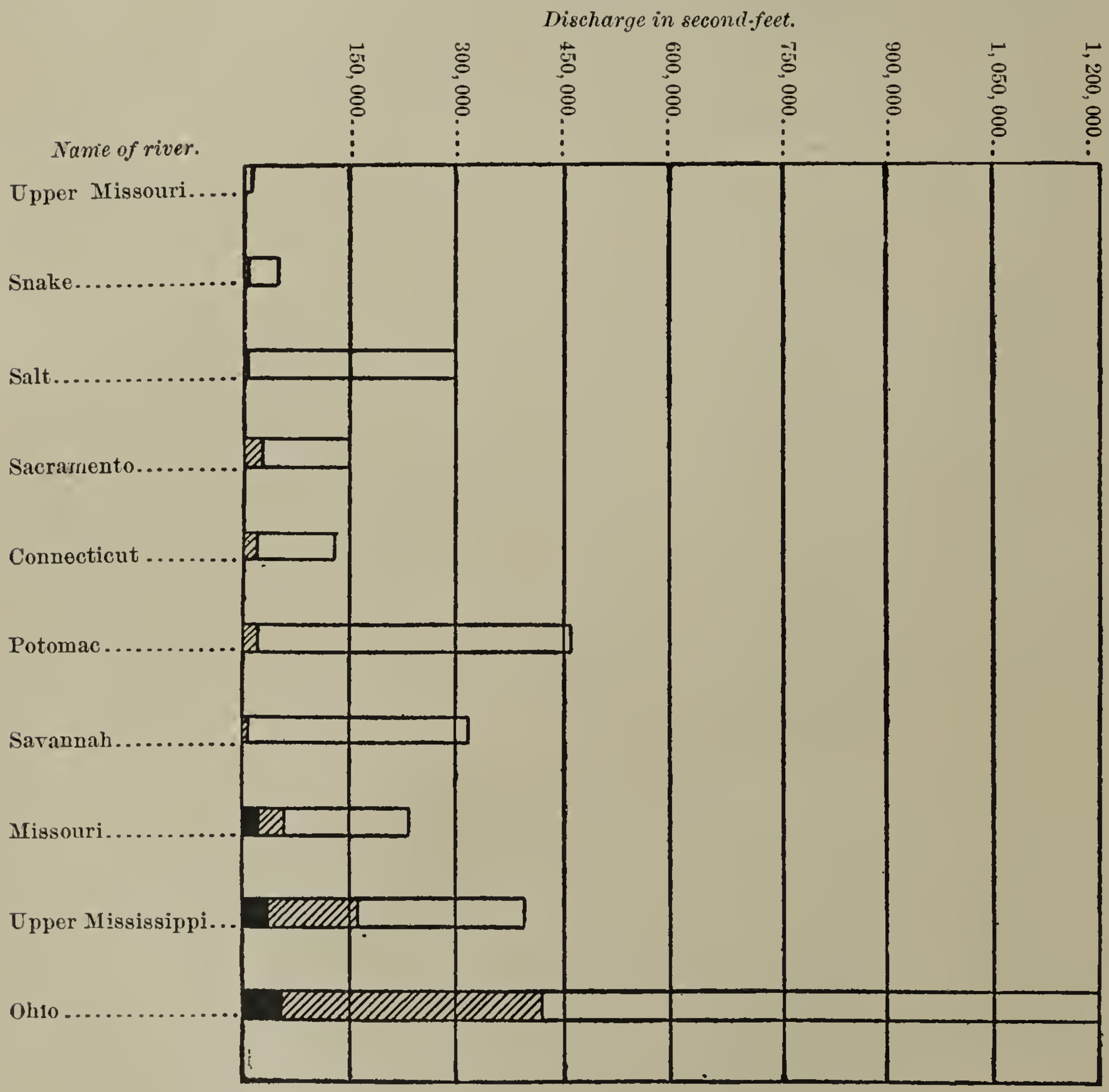


FIG. 43.—Diagram of discharges of large rivers of the United States.

RELATIVE RUN-OFF.

The run-off, or quantity of water discharged per unit of area of the drainage basin, is exceedingly variable, being dependent upon the topography and climate of the drainage basin, each of these embracing too many details to be enumerated in full. The difference in quantity is illustrated by Fig. 44, which shows in a diagramatic form the relative size of the basins drained and the amount of water flowing from them in the course of the year. Each circle in this diagram represents by its size the area of the drainage basin named, the latter being, as a matter of fact, exceedingly irregular in outline. The black line or bar at the right of each circle gives by its length the relative depth of run-off, the unit adopted being the depth in inches per square mile drained. The vertical lines indicate the number of inches; in the case of the West Gallatin, for example, a little less than 15 inches of water per year came from the drainage basin, or, in other words, if the water which flowed in the West Gallatin could be held without loss, it would cover a plain surface the size of the catchment area to a depth of less than 15 inches.

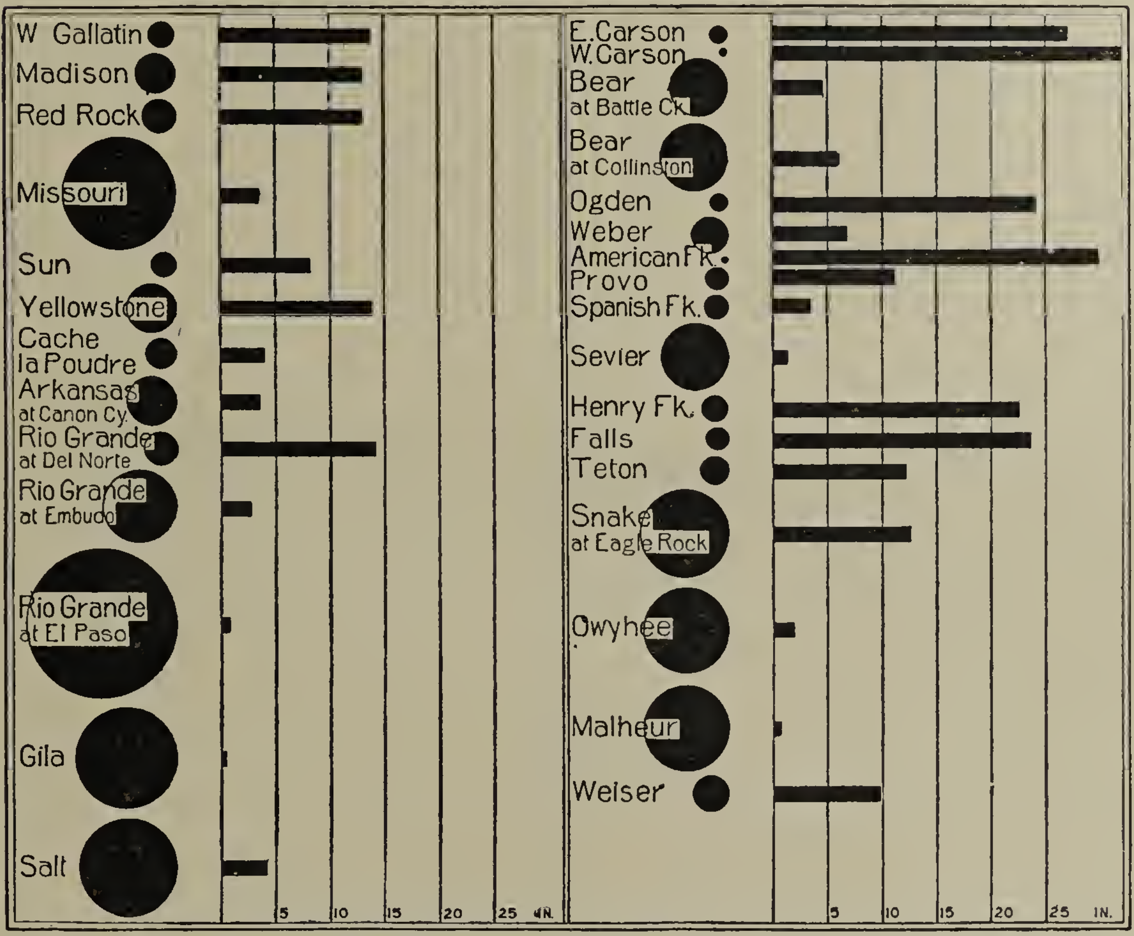


FIG. 44.—Diagram showing relative size of drainage basins and depth of run-off.

By the examination of this diagram, Fig. 44, it will be seen that as a rule the discharge per square mile is less from the large basins than from the smaller, or, in other words, the larger the basin the smaller the run-off. This is a fact noticed many years ago by engineers, and often recognized in computations of probable discharge of rivers based upon the area of the drainage basin and depth of rainfall. The decrease in run-off does not vary directly as the area of the basin, and for simplicity it has sometimes been taken as a function of the square root of the area. In this form it has been used in the formulas quoted in various works upon this subject.

The cause of the decrease in the proportion of run-off as a larger part of any drainage basin is taken is due principally to the fact that in the larger catchment areas there is usually included a greater percentage of level land, while in a small basin, embracing the headwaters of some stream, the catchment area may consist wholly of high, steep mountain slopes, upon which there is heavy precipitation and from which the water flows with great rapidity, the loss from evaporation being greatly reduced. This, for example, is the case in each instance shown in the diagram where the depth of run-off is great. The West Gallatin, Madison, and Redrock, the East and West Carson, and others have a catchment area composed almost exclusively of steep mountain slopes.

The decrease in depth of run-off with increase of area drained is shown in a striking manner in the case of the Rio Grande, the discharge of which beyond a point a short distance from the upper head waters increases but slightly, although the area tributary to the stream continues to grow larger and larger. In the case of this river, however, some allowance must be made for the peculiar condition of the drainage basin, embracing large catchment areas from which no water flows except in time of flood. In fact, as pointed out by R. T. Hill, the Rio Grande may be considered as a stream which has cut its way through a series of lost-river basins, and which, but for the outlet near El Paso, would be classified with the streams of the Great Interior basin.

There are occasional exceptions to the general rule that the average depth of run-off decreases as the basin grows larger; as, for example, in the case of the Bear, where, as shown by the diagram, the run-off at Collinston, below Cache valley, is greater than at Battle Creek, at the head of the same valley. This is due to the large run-off from the mountains on the east side of Cache valley, the topography being far more broken than at the head waters. The rule in this case will hold good if the streams from these mountains are considered as the main source of supply for the river and the water entering from other sources as tributary to these.

For convenience of reference the following table has been prepared, showing the mean annual run-off from several of the more important drainage basins, these being arranged in the order of proportion of discharge. This relation is expressed in this table not only in depth in inches, but also in second-feet per square mile drained, viz, the average discharge for the year in cubic feet per second is divided by the area in square miles from which the water comes. To obtain the depth in inches, it is necessary to multiply the second-feet per square mile by 13.575:

River.	Drainage area.	Run-off.	
		Depth.	Second-feet per square mile.
	Sq. miles.	*Inches.*	
West Carson	70	32·4	2·38
American Fork	66	30·0	2·22
East Carson	414	26·1	1·92
Ogden	360	25·0	1·84
Henry Fork	931	25·0	1·84
Falls	594	22·4	1·65
Snake	10,100	14·2	1·05
West Gallatin	850	14·0	1·03
Yellowstone	2,700	13·9	1·02
Truckee	1,519	12·9	·95
Madison	2,085	12·8	·95
Rio Grande at Del Norte	1,400	12·8	·95
Teton	967	12·1	·89
Provo	640	11·4	·84
Weiser	1,670	9·8	·72
Weber	1,600	8·3	·61
Sun	1,175	8·2	·61
Bear at Collinston	6,000	5·4	·40
Bear at Battle Creek	4,500	4·5	·33
Cache la Poudre	1,060	4·0	·30
Missouri	17,615	3·9	·29
Arkansas (6 years)	3,060	3·7	·27
Spanish Fork	670	3·5	·26
Average		13·8	1·01

As will be seen by this table, the depth of run-off varies greatly, ranging from over 32 inches in the case of the West Carson, which heads in the Sierra Nevadas, down to 3.5 inches for the Spanish Fork, whose catchment area is comparatively low and broad. The average of these twenty-three cases is 13.8 inches, or at the rate of a trifle over 1 second-foot per square mile. The catchments of these streams being well distributed throughout the mountainous area of the arid region, the average run-off as obtained in this way may be considered as being fairly representative of the discharge from the higher mountains of the West, and it has been used in this way in the preceding discussion.

FLUCTUATIONS OF RIVERS AND LAKES.

The average discharge, as discussed above, is a matter of first importance in considerations of water supply, but second only to it is a knowledge of the fluctuations which take place in the quantity delivered day by day or year by year. If the stream flowed at about a certain rate for long periods at a time or fluctuated with the seasons, returning to a former level each month, the subject of water control would be comparatively simple; but, unfortunately, the quantity of water flowing in a river is the resultant of so many variables, that it is impossible to predict with any degree of certainty what will be the amount flowing in the stream during the next crop season.

Farmers have learned by experience to estimate the possible discharge during the next succeeding crop season by the general appearance of the snows in the mountains, but beyond these rough approximations, as to whether the stream will be high or low, it is impossible to obtain definite knowledge. A study of the character of the fluctuations, however, which have taken place in past years throws light upon the probable behavior of the stream, and the longer such observations have been kept up the better able are the irrigators to judge of the probabilities.

The variation in the amount of water discharged day by day is shown graphically upon a number of plates published in the preceding annual reports, and also in a number of diagrams on the following pages. An examination of these diagrams shows that most of the rivers have a certain similarity in the character of the variation, namely, in that the water increases in amount during the late spring or early summer and then decreases to the minimum in September or October. This is the seasonal change which may be traced on nearly all diagrams of river height or discharge. Comparing the diagram for one year with that of another for the same stream, it is seen at a glance that although there is a certain similarity, yet no two actually coincide, the floods of one year coming earlier or later than those of another, and the total amount of water discharged differing by a large amount. There are thus, besides the change from day to day, two classes of fluctuations to be considered: First, the monthly or seasonal, which from its regularity may be called the periodic fluctuation, and second, the change from year to year, which from its great irregularity is known as the nonperiodic oscillation.

The periodic oscillation or variation in height or quantity of water in rivers and lakes is a matter which can be readily determined by measurements carried on through a series of years. It follows in a general way the changes of temperature and is affected to a certain extent by variations in the amount of rain or snow fall; the relation in this latter case, however, not being one whose connection can be readily traced, except in the case of rivers similar to the Gila, receiving a great part of their waters from violent local storms. These rivers, however, can scarcely be said to have a periodic oscillation, although the storms are more apt to occur during certain months of the year. On Pl. LIX of the third irrigation report[1] a diagram is given, showing the periodic oscillation of four rivers in connection with the average rainfall at a typical station in the basin of each stream.

The periodic fluctuation of a number of important rivers and lakes of the United States is illustrated in Fig. 45, which shows in a generalized form the average height for a number of years. At the top is shown the average gauge height of the Missouri river at Yankton, S. Dak., and below this of the Cache la Poudre and Arkansas rivers near the point where they leave the mountains in Colorado. In the case of the first stream the rise to the June flood is rapid and the decline is gradual, while in the other two the June flood is more abrupt, the water falling nearly to the minimum in August. Below these is given the average gauge height of the Arkansas at Fort Smith, Ark., showing the difference in the behavior of the river at a point farther away from the mountains. Here floods prevail from February until June, then falling to low water in September or October. The early floods come from the lower plains region, and these are followed in turn by high water from more elevated portions of the basin, the head-water floods coming last of all.

---

[1] Twelfth Ann. Rept. U. S. Geol. Survey, pt. 2, Irrigation p. 226.

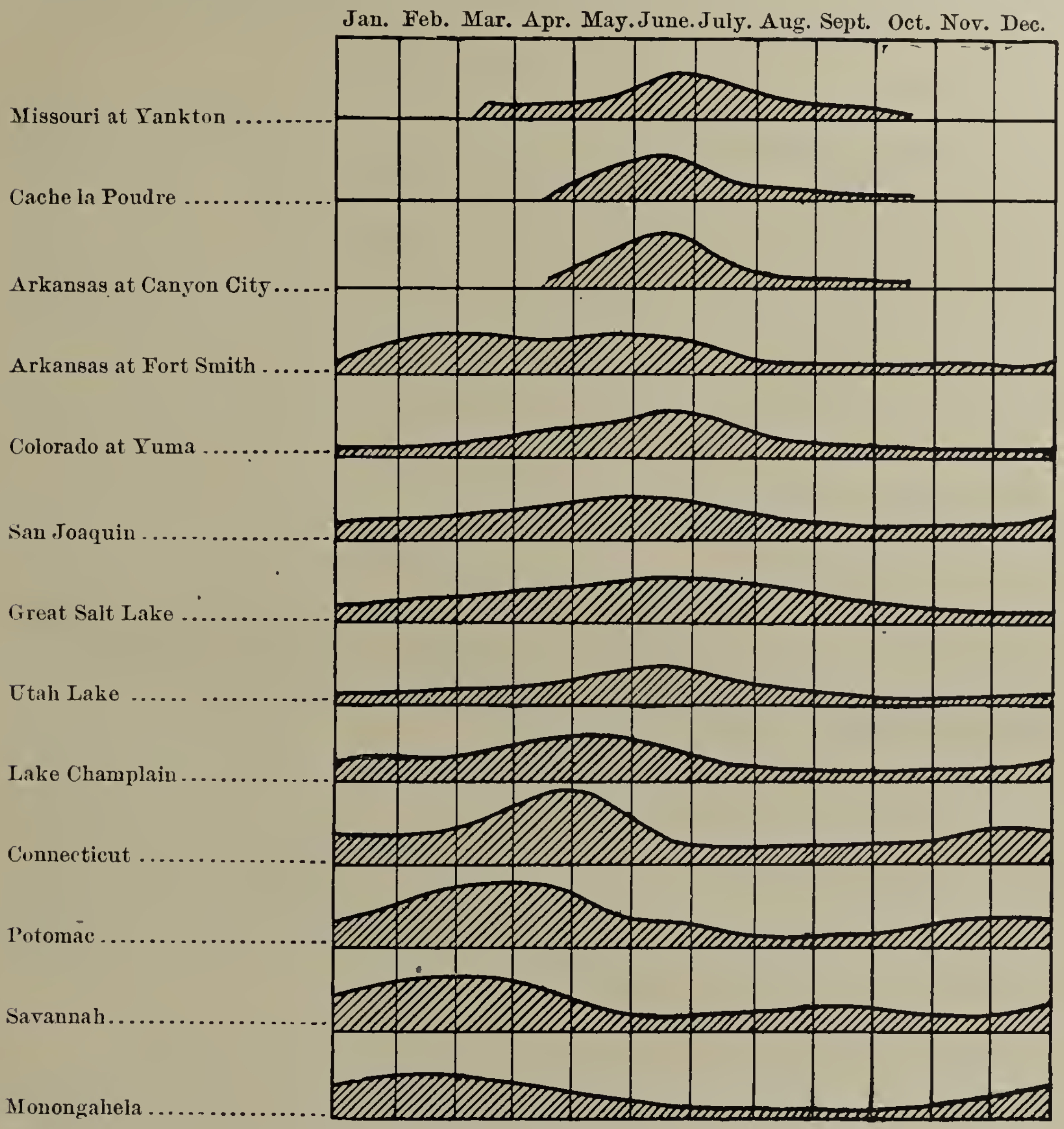


FIG. 45.—Diagram of periodic oscillations of water level.

The fifth figure from the top is that of the average gauge height of the Colorado river at Yuma, Arizona; the floods in this great stream culminating in June, as do those of the mountain streams of the arid region. Below this is the San Joaquin river of California, whose greatest discharge comes a little earlier in the season, the high water of winter beginning in December or even in November. The rise in both of these rivers is similar in many ways to that of Great Salt lake and

Utah lake, in Utah, the maximum in both of these occurring in June and the altitude of the surface falling gently toward winter. The last four diagrams on the page show the behavior of the principal Eastern rivers. This shows the later spring floods of the Northern rivers as compared with those farther South, the high water in the Savannah being earlier than in the Potomac and in the latter than in the Connecticut. The curve of river height of the Monongahela is typical of that for other tributaries of the Ohio.

NONPERIODIC OSCILLATIONS.

The nonperiodic oscillations give rise to the greatest concern on the part of the engineer and the irrigator, for while he can be reasonably certain regarding the character of the periodic variation he must at all times be on the watch for extraordinary occurrences for which there are no analogies. The rivers and lakes may for a time increase in volume or may apparently shrink so greatly as to cause serious alarm as to their permanence. In the humid regions these nonperiodic oscillations are of less moment, but in the arid regions, where water is always scarce, any change for the better or worse has an immediate effect upon the community as a whole.

The extent and character of nonperiodic oscillations may be illustrated by a few instances taken from streams in Colorado and other states. By reference to the table given below the average monthly discharge of the Cache la Poudre can be seen for the months from April to October inclusive for the years 1884 to 1891. This table shows that the average discharge for the seven months gradually decreased from 1,573 second-feet in 1884 to 373 second-feet in 1888, a decrease of 1,200 second-feet, or over three-quarters of the amount flowing in 1884. Since 1888 the discharge has increased, being in 1891 less than one-half that in the year first named. This, as can be imagined, is a most serious matter; for if streams are liable to shrink to a third or even a quarter of their value, the owners of the canals taking out the water. as well as the irrigators, must of necessity suffer.

Mean monthly discharge in second-feet of Cache la Poudre creek, Colorado.

Year.	April.	May.	June.	July.	August.	September.	October.	Average for seven months.
1884	219	2, 537	4, 812	2, 144	792	305	205	1, 573
1885	447	1, 419	2, 910	1, 857	656	272	203	1, 109
1886	*300	1, 309	1, 876	717	338	185	129	693
1887	*200	*1, 300	1, 401	735	307	175	*120	605
1888	181	483	1, 113	420	213	109	*90	373
1889	113	649	1, 338	514	187	67	69	419
1890	200	1, 044	1, 280	649	287	103	80	520
1891	144	1, 221	1, 900	541	228	138	118	613
Mean	225	1, 245	2, 079	947	376	169	126	738

* Estimated.

NOTE.—These data, obtained for the most part from measurements made by the state engineer of Colorado, have been published in different form in the Twelfth Annual Report of the U. S. Geological Survey, part 2, irrigation, page 348. The interpolations given above, since they have been computed for the whole month, differ somewhat from the figures in the report named, these latter relating to portions of months only.

A fluctuation of a similar character, although not as decided, is shown by the Arkansas, whose drainage basin is farther south, but in many ways similar to that of the stream above mentioned. As shown by the following table, the average discharge in 1886 was 1,572 second-feet, and in 1889 was only 523 second-feet, or about one-third of the former amount. In succeeding years, however, the discharge increased, the average in 1891 being 1,382 second-feet, or about two and a half times that of 1889.

Mean monthly discharge in second-feet of the Arkansas river at Canyon City, Colorado.

Year.	April.	May.	June.	July.	August.	September.	October.	Average for 7 mos.
1886	*600	2, 285	4, 190	1, 192	1, 110	1, 029	*600	1, 572
1887	*450	*1, 875	2, 602	2, 510	1, 284	844	*600	1, 452
1888	*1, 000	1, 440	2, 090	1, 350	932	605	*500	1, 131
1889	300	600	1, 374	602	340	220	223	523
1890	477	2, 090	2, 611	1, 571	670	519	531	1, 210
1891	857	2, 012	3, 291	1, 468	951	473	624	1, 382
1892	522	1, 241	2, 787	1, 798	769	435	511	1, 152
Mean	601	1, 649	2, 707	1, 499	865	589	513	1, 203

* The figures for 1886 and 1887 have been computed from the discharge measurements at Pueblo, allowance being made for the difference in drainage areas. See Eleventh Annual Report of the U. S. Geological Survey, part 2, Irrigation, pages 97–98; also Twelfth Annual Report, part 2, page 349.

That these oscillations, so strongly marked in the case of the Cache la Poudre and Arkansas, are not local may be seen by making comparisons with records of streams in other parts of the country. There are few rivers in the arid region, however, which afford records of considerable length, and the character of the oscillations can perhaps best be shown by records of the height of Utah lake, a fresh-water lake in Utah, and for a longer period by those for Great Salt lake, into which it empties. As shown by the following table Utah lake rose in height from 1884 to 1885 and then fell steadily until 1889, when it began to rise again. By comparison with the longer record of the height of Great Salt lake, it appears that this slight rise and continuous decline for a number of years are part of an irregular oscillation. The level of this latter lake has been falling, with occasional interruptions, for about fifteen years, this gradual decline being checked for a time by high water in 1885 and 1886.

Mean monthly height of Utah lake, Utah, above compromise line.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1884	—0·7	—0·3	0·3	0·8	2·2	4·4	4·6	3·5	2·6	2·4	2·3	2·2	2·02
1885	2·4	2·6	2·5	2·7	3·4	4·2	3·9	3·1	2·6	2·2	2·1	2·1	2·82
1886	2·2	2·3	2·3	2·5	3·0	3·2	2·6	1·7	0·9	0·5	0·4	0·6	1·85
1887	0·8	0·9	0·9	0·8	1·0	1·2	0·9	0·0	—0·7	—1·1	—1·2	—1·1	0·20
1888	—0·8	—0·5	—0·1	0·0	—0·2	—0·7	—1·2	—1·5	—1·8	—2·1	—2·5	—2·6	—1·17
1889	—2·5	—2·2	—1·6	—1·3	—1·9	—2·4	—2·9	—3·3	—3·7	—4·1	—4·0	—3·3	—2·77
1890	—2·8	—2·2	—1·6	—1·1	—0·5	0·1	—0·4	—0·9	—1·2	—1·4	—1·5	—1·7	—1·27
1891	—1·7	—1·4	—0·8	—0·2	0·3	0·8	0·1	—0·5	—0·9	—1·2	—1·3	—1·2	—0·67
1892	—0·8	—0·1	0·2	0·2	0·3	....	....	....	....	....	....	....	....
Means.	—0·43	—0·10	0·23	0·49	0·84	1·35	0·95	0·26	—0·28	—0·69	—0·71	—0·62	—0·11

NOTE.—These data have been obtained from a survey of Utah Lake and from records kept by various individuals, notably James Aitken, Lake Shore, Utah county, Utah. All records have been reduced to compromise line, viz, an arbitrary height marked by two monuments, one near the mouth of Jordan river, the other near the mouth of the old channel of Spanish Fork. This height, when established in 1885, by agreement between the counties of Salt Lake and Utah was assumed to be 3 feet 3.5 inches above low water. (See also diagram of fluctuations in Twelfth Annual Report of the U. S. Geological Survey, part 2, Irrigation, page 336, Fig. 229.)

Mean annual height of Great Salt lake, Utah, above Lake Shore zero.

Year.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1875...	......	......	......	......	......	......	......	......	5·7	5·6	5·5	5·7	......
1876...	6·0	6·1	6·3	6·4	6·8	7·5	7·6	7.2	6·8	6·7	*6·6	*6·6	6.7
1877...	......	......	......	......	......	......	7·3	......	......	6·1	5·8	......	6·0
1878...	5·9	*5·9	6·0	*6·1	6·2	6·3	6·1	*5·8	*5·5	*5·2	4·8	4·7	5·7
1879...	......	......	......	......	5·0	......	......	......	......	......	2·5	2·6	4·0
1880...	2·7	2·6	2·8	2·9	3·2	3·3	3·2	2·8	2·3	1·9	1·7	1.7	2·6
1881...	2·0	2·5	2·6	2·7	3·1	3·4	3·2	2·8	2.3	2·1	2·0	2·1	2·6
1882...	2·2	2·3	2·4	2·6	2·9	2·9	2·6	2·3	1·7	1·4	1·4	1·4	2·2
1883...	1·4	1·5	1.5	1·7	*1·8	*2·0	*2·1	*2·0	1·7	0·9	0·5	0·4	1·5
1884...	0·4	0·5	0·8	1·2	1·8	2·5	2·8	2·5	2·4	2·3	2·2	2·3	1·8
1885...	2·6	2·8	3·0	3·3	3·6	4·0	4·2	4·0	3.5	3.3	3.2	3·2	3·4
1886...	3·5	3·8	4·1	4·3	4·5	4·6	4·2	*4·0	*3·8	3·6	3·4	3·6	3·9
1887...	3·5	3·5	3·8	3·9	4·0	4·0	3.8	3.5	2·9	2.6	2.5	*2·5	3·4
1888...	2·6	2·7	2·8	3·0	2·9	2·7	2·3	2·0	1·6	1·3	0·9	1·0	2·2
1889...	1·0	1·2	1·5	1.2	1.2	0.9	0.3	—0·3	—1·0	—1·0	—0·9	—0·9	0·3
1890...	—0·8	—0·4	0·0	0·2	0·7	1·0	0·8	0·5	0·0	—0·4	—0·4	—0·4	0.1
1891...	—0·3	—0·3	0·0	0·1	0·3	0·4	0·1	—0·3	—0·5	—0·6	—0·7	—0·8	—0·2
Mean.	2·33	2·48	2·68	2·83	3·20	3.25	3·37	2·77	2·58	2·56	2.41	2.23	2·72

* Estimated.

NOTE.—The data from which the greater part of these figures have been obtained are to be found in Gilbert's Monograph on Lake Bonneville, pp. 233–238.

These facts are best shown by reference to Fig. 46, which gives in graphic form the averages of the mean values shown in the above four tables. The rapid decrease of water in each of the rivers and lakes just mentioned clearly appears, although the maximum and minimum points do not happen on the same years in each case. The longer record of Great Salt lake gives a hint as to what may have been the amount of water in Utah lake, and possibly in the streams during preceding years. According to this diagram the height of Great Salt lake has been as a whole steadily decreasing, but that this is only the latter part of a great fluctuation, a return from unusually high water to conditions more nearly normal, can be seen by referring to a diagram contained in Gilbert's monograph on Lake Bonneville.[1] According to this figure, the high water of 1876 is not far from the maximum for this century at least, while the low water of 1890 may be considered as being above the average height previous to 1865.

The most prominent feature shown in Fig. 46 is the unusually high water prevailing about 1885. This is a condition which has been noticed in many other localities, namely, that from 1884 to 1886 there was an extraordinarily large stream discharge and that lakes increased in height, in some localities the rise reaching its maximum in 1884, in others not until later. For comparison with the rivers of Colorado and the lakes of Utah just mentioned may be given the Colorado river and the San Joaquin, the former draining the western part of Colorado, the eastern half of Utah and nearly all of Arizona, and the latter receiving its waters from the western slope of the Sierra Nevadas. These, as will be seen by examination of Fig. 47, show a great rise in

---

[1] Lake Bonneville, by Grove Carl Gilbert, Washington, 1890, Mon. U. S. Geol. Survey, Vol. 1, page 243, Fig. 33.

1884, followed by a decline more or less gradual and an increase toward the end of the decade. On this same diagram is given a curve, showing the variation in rainfall at all of the stations in the western part of the United States, where record has been kept for the past decade. The average annual rainfall, as shown on Fig. 47, agrees quite closely with the behavior of the rivers, more closely, in fact, than would have been anticipated. It shows that, taking the country as a whole, there was an extraordinary amount of precipitation during 1884. At about that time the great increase in rainfall was noticed and popularly attributed to the effects of cultivation and to other causes under the control of man. That these fluctuations in precipitation are widespread,

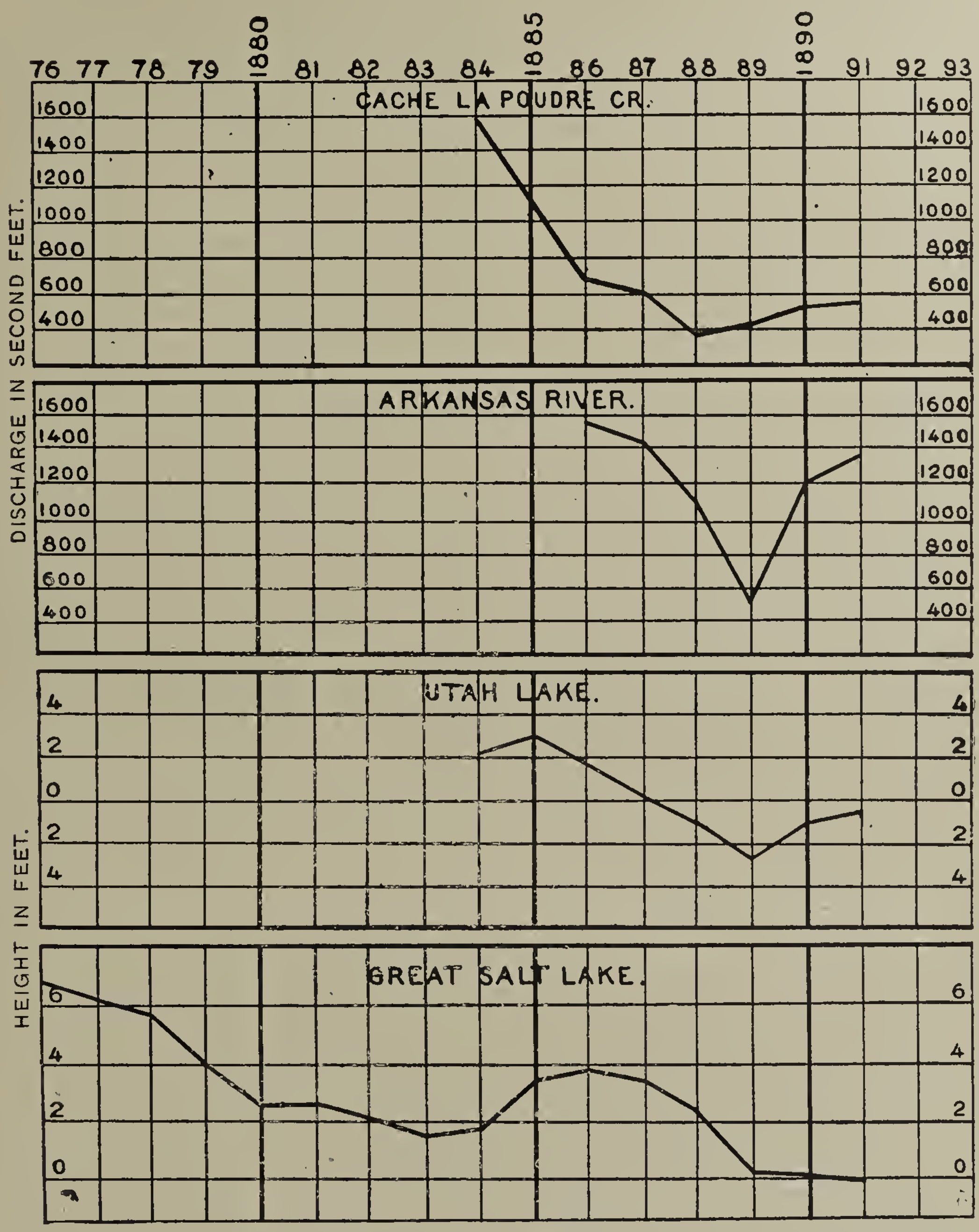


FIG. 46.—Diagram of nonperiodic oscillations of various rivers and lakes.

and wholly remote from human influence even in the slightest degree, hardly needs discussion at present.

For comparison with the fluctuations of Great Salt lake it is interesting to note the average height of water in the Great Lakes, viz, Superior, Michigan, Erie, and Ontario, during the same years. This is given on Fig. 48, and an examination shows that in a minor degree there is a certain coincidence. For instance, there are in both cases times of relatively high water in 1870, 1877, and 1885–'87, after which date both fall. These points of agreement, however, are equaled or surpassed in importance by differences in the general form of the curve as a whole, Salt lake having unusually high water from 1870 to 1880, while the diagram for the Great Lakes shows almost the reverse. The important distinction in the two should not be overlooked, namely, that Great Salt lake has no outlet to discharge its excess water, while the Great Lakes have.

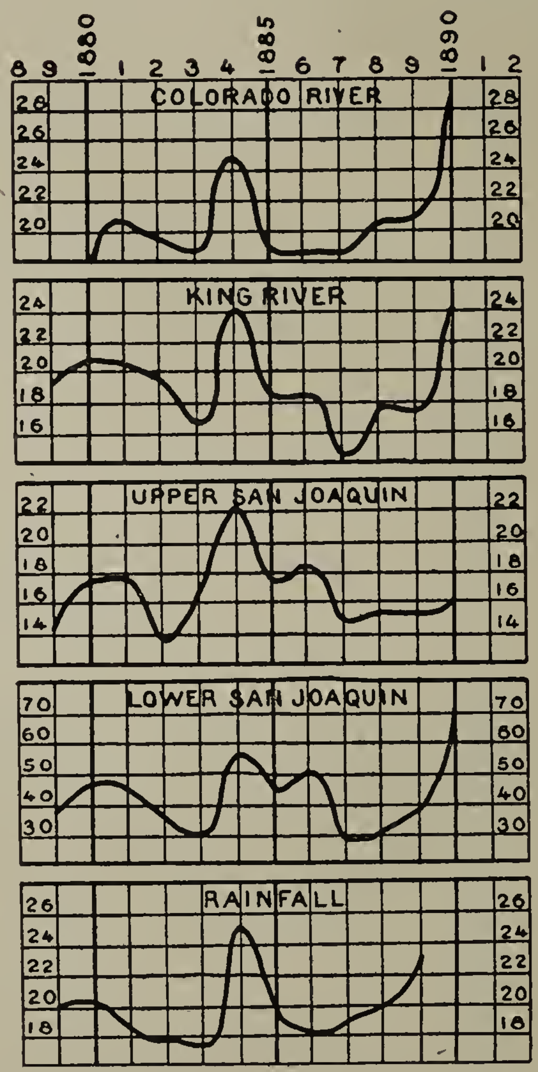


Fig. 47.—Diagram of nonperiodic oscillations of Colorado, King, and San Joaquin rivers.

The nonperiodic variations in height in rivers and lakes, while taking place in humid regions, are not as generally noticed as in the case

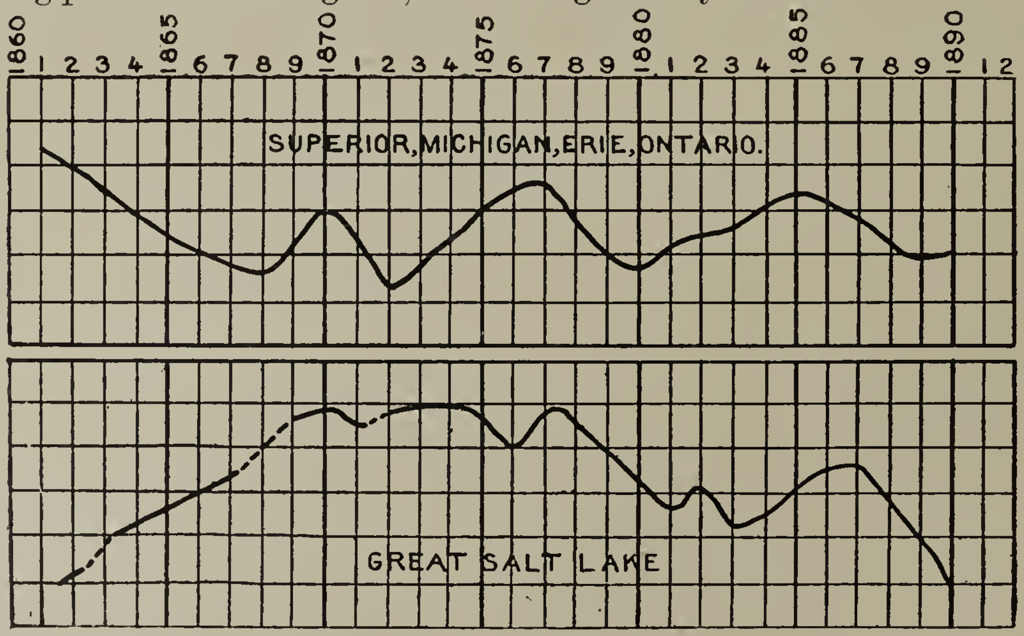


Fig. 48.—Diagram showing comparison of nonperiodic oscillations of the Great Lakes with Great Salt lake.

of the waters of arid lands, because, water being far in excess of all demands, an increase or diminution passes unheeded by the public, although the same amount of change in the arid region would be of vital importance. Occasionally, however, circumstances occur by which these

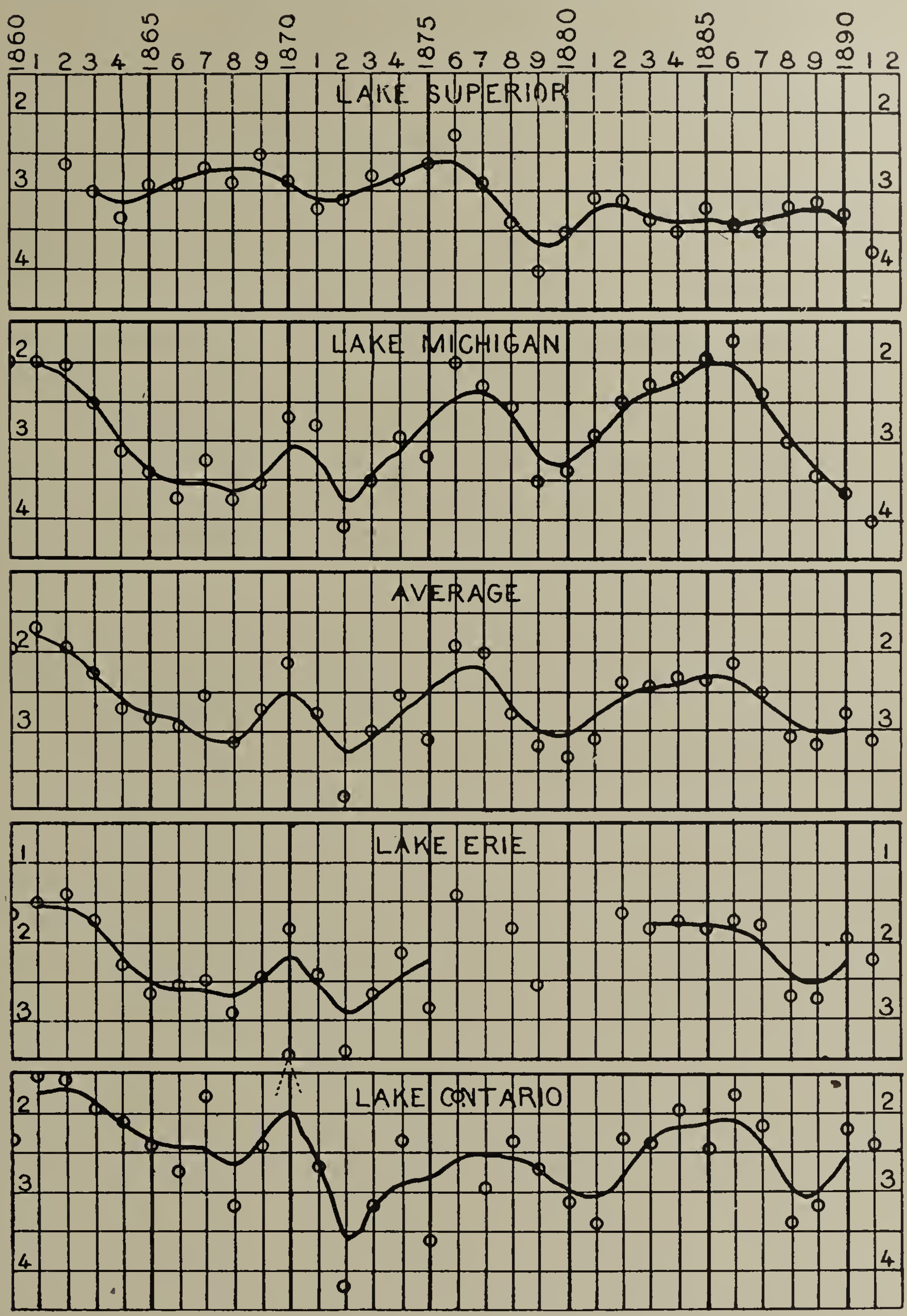


Fig. 49.—Diagram of nonperiodic oscillations of the Great Lakes.

oscillations are forced upon public attention, as, for instance, in the case of Lake Michigan, which from 1879 rose steadily until 1886, and alarm was excited for the safety of the wharves and other property at Chicago. In the following years, however, the lake fell more rapidly than it rose, until in 1891 there was another alarm, but from the opposite cause, namely, that the lake was retreating so rapidly that it threatened to leave the wharves high and dry.

Observations have been kept of the height of the Great Lakes for over thirty years, giving one the best records of oscillations of water level in this country. It is instructive to examine this record, shown in the following table, in connection with the present subject, and to note the changes that have occurred during three decades. These facts are also on Fig. 49, which gives diagramatically the mean annual water level at stations on lakes Superior, Michigan, Erie, and Ontario, the small circles indicating the average height for the year noted at the top of the figure. The undulating line passing through some of these points is a smoothed-out curve, constructed by the use of the simple formula $b'=\frac{1}{4}(a+2b+c)$, in which b' is the smoothed value for any year, a the observed value for the year preceding, b the observed value for the year under consideration, and c for the succeeding year:[1]

Mean annual height below plane of reference.

Year.	Superior.	Michigan.	Erie.	Ontario.	Mean.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1860	....	2·01	1·61	2·31	....
1861	....	2·03	1·53	1·53	....
1862	2·68	2·07	1·42	1·54	1·93
1863	3·02	2·54	1·71	1·94	2·30
1864	3·34	3·16	2·31	2·12	2·73
1865	2·93	3·40	2·67	2·38	2·85
1866	2·94	3·73	2·53	2·72	2.98
1867	2·72	3·29	2·50	1·77	2·57
1868	2·91	3·78	2·88	3·19	3·19
1869	2·58	3·66	2·46	2·34	2·76
1870	2·89	2·75	1·83	1·26	2·18
1871	3·25	2·82	2·42	2·63	2·78
1872	3·17	4·10	3·38	4·16	3·70
1873	2·84	3·45	2·67	3·09	3·01
1874	2.88	2·96	2·16	2·34	2·59
1875	2·75	3·21	2·83	3·63	3·11
1876	2·42	2·08	1·41	1·77	1·92
1877	2·87	2·31	....	2·96	....
1878	3·37	2·62	1·82	2·36	2·54
1879	4·01	3·54	2·58	2·71	3·21
1880	3·55	3·40	....	3·11	....
1881	3·10	2·88	....	3·42	....
1882	3·14	2·51	1·63	2·35	2·41
1883	3·37	2·36	1·84	2·40	2·49
1884	3·51	2·26	1·77	1·95	2·37
1885	3·27	2·01	1·87	2·49	2·41
1886	3·45	1·77	1·76	1·77	2·19
1887	3·51	2·41	1·80	2·19	2·48
1888	3·22	3·03	2·49	3·37	3·03
1889	3·18	3·56	2·75	3·18	3·17
1890	3·31	3·68	2·05	2·23	2·82

---

[1] In this connection see preliminary report by Charles A. Schott on "Fluctuations in the Level of Lake Champlain and Average Height of its Surface above the Sea," Appendix No. 7, An. Rep. U. S. Coast and Geodetic Survey, 1887, p. 171.

Mean monthly height below plane of reference.

Month.	Superior.	Michigan.	Erie.	Ontario.	Mean.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
January	3·44	3·35	2·42	3·08	3·07
February	3·65	3·31	2·49	3·06	3·13
March	3·70	3·15	2·30	2·84	3·00
April	3·62	2·94	1·83	2·26	2·66
May	3·22	2·69	1·51	1·83	2·31
June	2·96	2·45	1·35	1·68	2·11
July	2·71	2·37	1·39	1·74	2·05
August	2·62	2·43	1·55	2·02	2·16
September	2·61	2·62	1·80	2·41	2·36
October	2·66	2·84	2·11	2·79	2·60
November	2·85	3·09	2·34	3·06	2·84
December	3·20	3·30	2·39	3·09	3·00

This matter of the nonperiodic fluctuation of rivers and lakes and its connection with variations of precipitation has been discussed by many writers in connection with oscillations of climate. The most elaborate discussion of the subject is probably that by Dr. Edward Brückner.[1] In his work is given an elaborate discussion of data concerning the variations of rainfall and temperature, also of wind movement and other climatic factors, accompanied by diagrams exhibiting these facts in concise form. This volume has been preceded by pamphlets upon the oscillations of water level in the Caspian, the Black, and the Baltic seas in their relation to weather and on the question as to what extent is the present climate constant.

The principal fact taught by the examination of the fluctuations of the rivers and lakes of not only the arid regions, but of the United States as a whole, is that these are due to climatic forces, not only continental, but even world-wide in extent. It is no uncommon thing for a river to sink to one-half of its average volume in any one year or double it the next. These matters, however, can not be regulated or affected, except perhaps in a very slight degree, by any action on the part of mankind. There is an idea widely current that the removal of the forest cover at the head waters of a stream acts injuriously in many ways and causes greater fluctuations in the quantity discharged, especially in time of flood. This is a matter, however, exceedingly difficult to prove on account of this enormous variation in volume which takes place in every stream, whether in a forested country or not, the fluctuation due to climatic changes being enormously greater than that which can be attributed in any way to the result of forest destruction.

VARIATIONS IN PRECIPITATION.

The changes in the amount of rainfall and snowfall at various localities are by no means comparable among themselves, one locality showing a slight increase in any one year and another a decrease; but, taking the averages of large numbers of observations, there are found to be, as before shown, certain general departures on one side or the other, one year being marked by an unusual amount of precipitation and another by deficiency. These averages of rainfall measurements do not agree as closely as might be expected with the statements of farmers as to droughts or good years, for they do not take into account the distribution of the rain by seasons; that is to say, there may be an unusual drought at the critical season of the year accompanied by great crop losses, and yet, taking the year as a whole, the deficiency of rainfall may not be especially notable. Therefore great reliance can not be placed upon the results of total annual rainfall measurements alone.

---

[1] Klimaschwankungen seit 1,700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit, Von Dr. Eduard Brückner. Wien und Olmütz, Ed. Hölzel. 1890.

The attempt to connect the discharge of any one stream with the measurements of rainfall in the basin is unsatisfactory, unless the catchment area is unusually small and records of the rainfall have been kept at a large number of places well distributed over this area. This is a matter almost impossible of achievement in the arid region, where the greater part of the available water supply comes from high mountainous areas almost if not quite uninhabitable. Until this apparently impossible condition is fulfilled, namely, the keeping of many rainfall records in each catchment area, it will be hopeless to attempt to connect the rainfall and river flow in any detailed manner.

In a general way the average of the rainfall measurements over several states begins to show a coincidence with the fluctuations of the streams, although in detail the matter seems confused. This is shown in Fig. 47, as previously mentioned, and might be brought out in connection with change of level in many of the streams and lakes. The matter is one, however, concerning which the data at present available are still too limited for satisfactory discussion.

The periodic oscillations of rainfall throughout the year are capable of more satisfactory treatment than the fluctuations year by year, from the fact that there is a general agreement in stations near each other, changes in the distribution of rainfall by months being found to take place slowly as progress is made across the continent. A diagram therefore, prepared from a long record at any one station in one of the smaller states of the West, is found to be applicable in the main features to the greater part if not the whole area; that is to say, if May is the month of maximum rainfall at any one point it probably is for all localities in the state, while in the localities adjoining it is highly probable that the time of maximum rainfall will be either immediately before or after that of the given state.

Fig. 50 has been prepared to show the average distribution of precipitation by months at a few stations in the western half of the United States. It brings out in sharp contrast the differences in the character of the rainfall on opposite sides of the arid region. On the Pacific coast summer droughts are the rule, while on the eastern side of the arid region the greater part of the rainfall is during summer. Between these two the gradual transition from one to the other is well marked in nearly every instance. This matter of the characteristic distribution of precipitation throughout the year has been systematically discussed by Gen. A. W. Greely in his report upon irrigation and water storage in the arid regions,[1] and also in a paper presented before the National Geographic Society upon rainfall types of the United States.[2] He points out that there are several distinct and simple types of rainfall, each of which can be represented graphically by a curve with a single bend or inflection, the average monthly amount of precipitation increasing steadily from a minimum to a maximum and then diminishing in unbroken progression. Each of these simple types of rainfall is shown to have some relation to the movement of winds from some one great body of water—the Pacific Ocean, the Gulf of California, the Gulf of Mexico, etc. Besides these simple curves are composite types, shown graphically by two inflections, there being in each a primary and a secondary minimum and maximum.

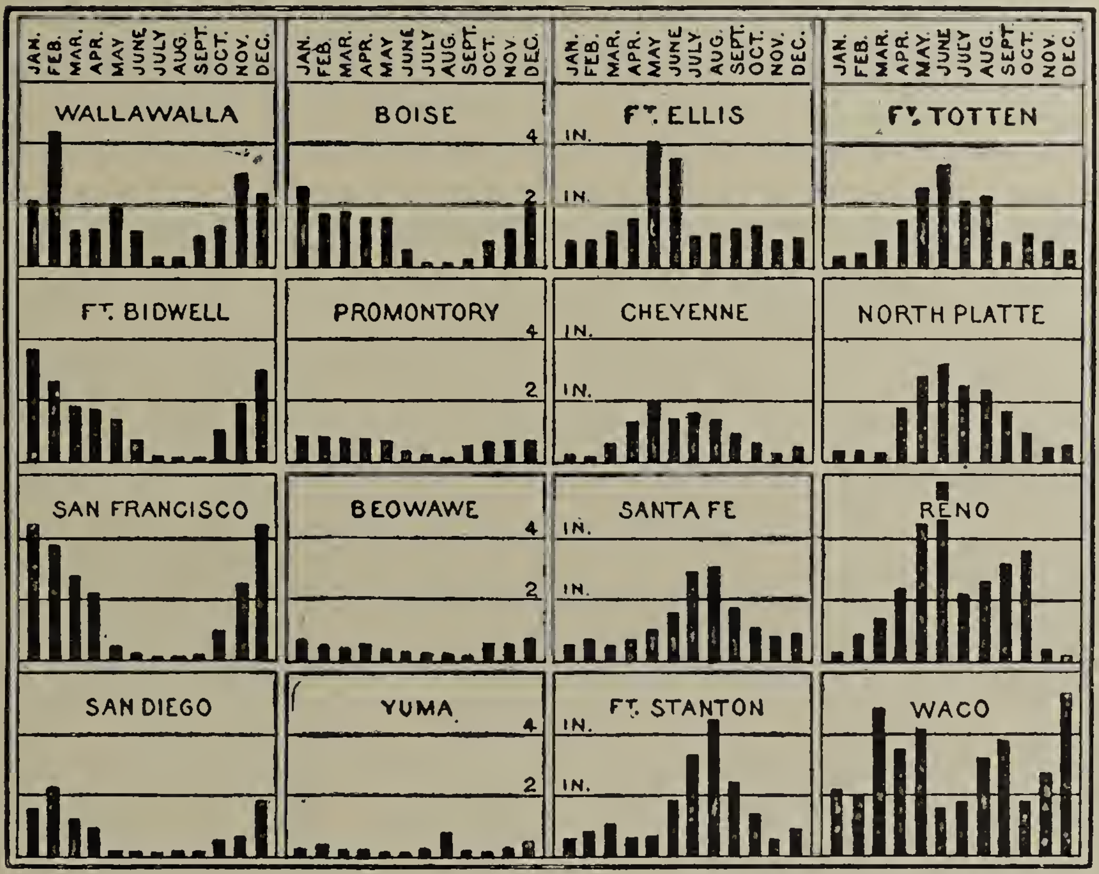


FIG. 50.—Diagram of the distribution of the mean monthly precipitation at sixteen stations in western United States.

The diagram, Fig. 50, shows at least three of the simple types and several of the composite forms. In the cases of the portions of the diagram illustrating the distribution of precipitation at Fort Bidwell and San Francisco a general curve might be sketched connecting the tops of the small columns. This would represent fairly well the Pacific type of rainfall, which is characterized by heavy precipitation during the winter and prolonged droughts in summer. In a similar way a curve drawn through the part of the diagram for Santa Fe would represent the Mexican type, which is notable for the very heavy precipitation in August. The third simple type is perhaps best shown on this diagram by the conditions at North Platte, Nebraska. This has been named the Missouri type, from the fact that it obtains throughout the watershed of the Missouri River and its principal tributaries. As shown by the diagram, the rainfall during the winter is very light, the greatest amount of precipitation being in late spring and early summer.

---

[1] Fifty-first Congress, second session, House of Representatives, Ex. Doc. No. 287, Washington, 1891. Report on the climatology of the arid regions of the United States with reference to irrigation. By Gen. A. W. Greely, Chief Signal Officer, U. S. Army.

[2] The National Geographic Magazine, Vol. V, pp. 45-60. Rainfall types of the United States. Annual Report, by Vice-President Greely.

SUBSURFACE WATERS.

The water obtained from rocks beneath the general surface of the country, although relatively small in amount when compared with that from streams, has great importance, from the fact that dependence must necessarily be placed upon this in many localities where running water can not be had. Not only is agriculture benefited indirectly by water from wells convenient for household use and stock purposes, but in many instances a supply sufficiently great for irrigation in a small way has been obtained. Water for irrigation is lifted from the wells generally by means of windmills or by machinery driven by steam or horse-power. In some localities the structure of the rocks is such that water rises to the surface and overflows, artesian wells being obtained by drilling to depths ranging from a hundred to a thousand feet or more.

The total number of artesian wells in the western part of the United States in 1890 was 8,097, as ascertained by the census of that year. These were found in North and South Dakota, Nebraska, Kansas, and Texas, and the states and territories to the west of these to the Pacific coast. Of this number, 3,930 were employed to a greater or less extent in irrigation, watering 51,896 acres, or 1.43 per cent of the total area irrigated. The residue of the wells were undoubtedly of benefit to agriculture to some extent; their principal value, however, being in the fact that they furnished supplies for municipal and domestic purposes, and also for cattle when the wells are in the vicinity of grazing lands.

No statistics have been obtained concerning the ordinary wells from which water is pumped or drawn by various means, but there is found in nearly every locality water saturating porous rocks near the surface in all places except on desert areas. On the Great Plains, for example, in western Nebraska and Kansas, it is sometimes necessary to go to depths of from 100 to 300 feet or more before water-bearing strata are reached, but throughout the arid region as a rule wells are successfully dug to a less depth. The widespread occurrence of water in pervious layers of the earth's crust, and sometimes in such quantities as to appear almost inexhaustible, has given rise to the notion that it flows in great channels very much as do the rivers of the surface, but covered from sight by rocks and soils. There are a few instances where underground watercourses actually occur, but these are extremely rare and are extraordinary in their nature, being found only in the great limestone deposits or among the lava flows of recently extinct volcanic regions.

In a majority of cases subsurface water occurs merely as moisture saturating the rocks. If these are unconsolidated and porous the quantity of water contained in the interstices is in the aggregate very large, while in the case of the hard compact granites or slate the proportion is extremely small. That all rocks which form the crust of the earth contain a certain amount of water can usually be shown by drying any of them and noting the loss in weight. The sands and gravels washed down from adjacent heights and filling depressions are particularly well adapted to hold moisture, and it is from these, as is well known, that the greatest quantities of water are obtained.

The behavior of the waters in these sands is still a matter of inquiry, and is not clearly understood. For instance, one leading question is: Are these stationary, or do they flow freely from place to place? It is probable that to a certain degree both of these conditions are found in nature. In a small valley entirely inclosed the water accumulates in the sands until they are saturated and the moisture approaching the surface of the soil begins to be evaporated. The matter then adjusts itself until a balance is reached between the amount which flows in and that which is evaporated, the level of water rising until the loss is equal to the inflow. If a well be made in this sand basin and the water drawn upon, the level of moisture in the immediate vicinity of the well is immediately lowered. The influence extends only with great slowness towards the edge of the basin, however, the water level not as a whole falling at once, as would be the case in drawing from a large open body, the place of the water removed from the center being slowly occupied by a gradual progression of moisture from the sides.

Instead of a small basin, if one of indefinite size be considered, there is seen a condition of things similar to that which takes place in a broad extent of country. The moisture at the lower limit of a large plain escaping either in springs or by evaporation is gradually replaced by the slowly progressing water, which percolates with a rate varying with the fineness of the rock or sand layer. The amount of water which can be taken from underground sources is limited not so much by the total quantity in the area, as by the rate at which it can flow through these sands or gravels, and after the first wells have drawn upon the supply already stored in the immediate vicinity the amount which can be taken afterwards is governed by the speed with which the moisture can progress to the place from ever-widening limits. In lost river basins and on low lands in the vicinity of irrigated areas the amount and behavior of this subsurface water becomes a factor of great local importance.

Popular interest, especially in the subhumid regions, has been aroused concerning subsurface or ground waters, and statements as to their distribution, quantity, and availability, especially for irrigation, have been eagerly received. The somewhat misleading and indefinite term "underflow" has been applied to these waters, and many persons awakening for the first time to a realization of their presence have received exaggerated impressions or have magnified the importance of phenomena previously known to engineers and geologists. Extravagant reports have been made as to the results of rude experiments, and many persons have been induced to believe that it was practicable to irrigate large portions of the subhumid region by means of the ground waters conducted to the surface of the gently sloping plains through long tunnels or open channels. Acting on this belief, thousands or even hundreds of thousands of dollars were expended, mainly in the years 1890 and 1891, in the construction of such projects, principally along or in the valleys of the Platte and Arkansas rivers. So far as can be ascertained by examination and measurement none of these projects can be said to be successful, although in a number of cases small quantities of water are obtained from the long, deep channels which penetrate the pervious beds of sand and gravel.

In each of the instances of these so-called underflow canals the level of the ground water, or what is known to engineers as the water table, is lowered in the immediate vicinity of the cut or excavation, and the upper part of the pervious beds being drained, a new slope of the water table is found, this being adjusted to the altered conditions. The progress of the water down this new slope is, so far as can be ascertained, practically constant, except as modified by local rains and changes of temperature. The quantity of water actually obtained, although large in one sense, as, for example, when compared with that from an ordinary well or the amount utilized for domestic supply, is almost insignificant with reference to the irrigation of any considerable body of land. The projectors of these irrigating schemes often failed to appreciate not only the fact that ground waters must in their very nature move slowly, but also that even in comparatively humid countries large volumes of water are necessary to conduct irrigation on an extended scale.

COST AND VALUE OF WATER SUPPLY.

The average first cost of water for irrigation throughout western United States has been ascertained to be at the rate of $8·15 per acre, while its value, wherever the rights can be transferred without the land, is $26. Applying these figures to the total acreage as ascertained by the last census, the total first cost of irrigating the lands from which crops were obtained in 1889 was $29,611,000, and the total value of the water rights was $94,412,000, the increase of value being $64,801,000, or 218·84 per cent of the investment. This latter sum may be taken as representing the value of the supply utilized. The average annual expense of maintaining the water supply was $1·07 per acre, or an aggregate of $3,794,000, this being the amount expended in keeping the canals and ditches in repair and free from sediment.

The estimated first cost of the irrigated lands from which crops were obtained in 1889 was $77,490,000, and their present value, including improvements, $296,850,000, showing an increased value of $219,360,000, or 283·08 per cent of the investment in the land, not taking into consideration the water. The average value of the crops raised was $14.89 per acre, or a total of $53,057,000. These figures have been introduced to exhibit the cost and value of irrigation in the arid regions. The value of the unutilized water supply can scarcely be estimated until more accurate information is obtained concerning the total amount of water and the acreage that it can be made to cover. By making certain assumptions, however, a rough estimate can be arrived at.

Taking the average first cost of water at $8·15 per acre and its present value at $26 per acre, the difference, $17·85, may be assumed as the value of the water as it flows in the stream. If 1 cubic foot per second will water 100 acres, then the value of 1 second-foot is $1,785. Taking the figures given on page 10, as to the total quantity of water probably available, viz, 360,000 second-feet, the total value of this water is $642,600,000. These figures obviously have no claim to accuracy, but merely indicate that, calculated on the most conservative basis, the water supply of the arid country must be ranked among the most important of its undeveloped mineral resources.

PRINCIPAL DRAINAGE BASINS.

In order to enter upon a detailed discussion of the water supply of the arid region it is necessary to consider the different portions in turn, and for this purpose the best method of grouping the facts is by natural divisions, viz, by drainage basins. The political divisions into states and counties unfortunately do not coincide with lines of drainage, except in a few instances, so that the discussion of water supply according to these arbitrary lines is less satisfactory than by the way first mentioned. The small map (Fig. 51) shows the relative location and area of the larger drainage basins of the west and their position with reference to the states and territories, the size of these in square miles being shown in the accompanying table, page 33. According to this table the total area of the part of the United States west of the 100th meridian is 1,380,175 square miles, not including thirty-six counties in the western portion of Oregon and Washington, the aggregate area of these, including water surface, being 61,840 square miles. Adding this amount, the total area of the land and water surface west of the 100th meridian is 1,442,015 square miles. The thirty-six western counties of Oregon and Washington above mentioned have been deducted because of the fact that in a study of water supply and irrigation it has been found convenient to omit from consideration these comparatively well-watered areas. The 1,380,175 square miles above mentioned include the area of several large lakes, the principal of these

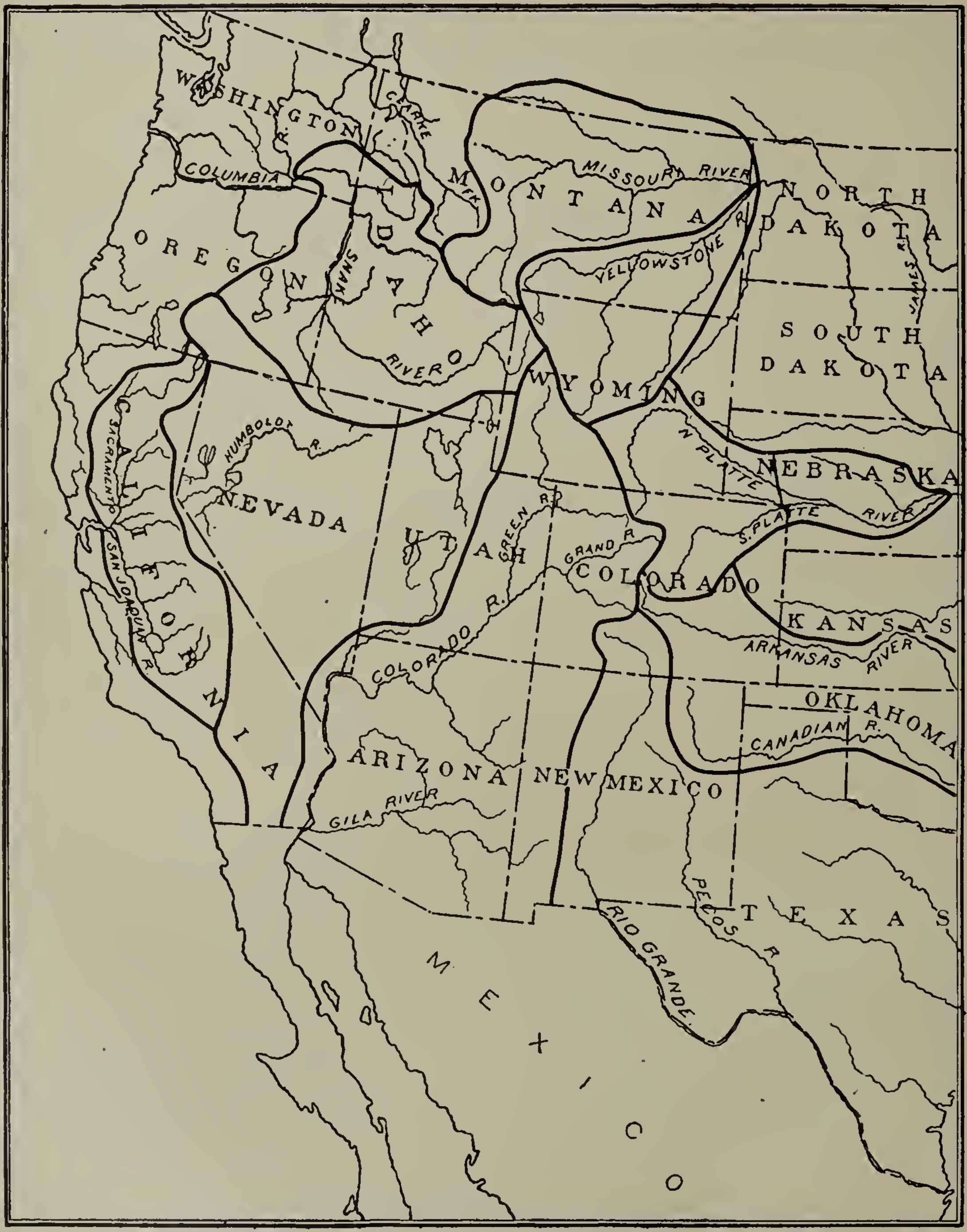


Fig. 51.—Index map of large drainage basins.

being in Utah, California, and Montana. The aggregate area of these water surfaces is 8,215 square miles, which being deducted gives the total area of land surface used on page 33.[1]

The order usually adopted is that by which the head waters are first considered and then the tributaries in succession. The large drainage

---

[1] The areas of States and counties are those given by Henry Gannett, geographer of the Eleventh Census, in census bulletin No. 23, January 21, 1891.

Area in square miles of principal drainage basins by states.

Drainage basin.	Total.	Arizona.	California.	Colorado.	Idaho.	Kansas.[a]	Montana.	Nebraska.[a]	Nevada.	New Mexico.	North Dakota.[a]	Oregon.[b]	South Dakota.	Texas.[c]	Utah.	Washington.[d]	Wyoming.
Total area including water surface	1,380,175	113,020	158,360	103,925	84,800	22,850	146,080	35,800	110,700	122,580	40,020	70,528	40,840	114,970	84,970	32,842	97,890
Upper Missouri[e]	81,778						81,018										760
Yellowstone	69,683						36,312				250						33,121
Cheyenne, etc.[f]	114,300						3,750	17,910			39,779		40,840				12,030
Platte (North and South)	57,320			[g] 22,230				10,850									24,240
Kansas	23,072			5,332		10,700		7,040									
Arkansas	37,760			30,720		7,040											
Canadian	40,630					5,110				16,900				18,620			
Red	15,800													15,800			
Rio Grande, etc.[h]	160,457			7,527						72,380				80,550			
Green above Grand	47,225			10,332											15,916		20,977
Grand above Green	26,167			22,294											3,873		
Lower Colorado, etc.[i]	114,115	56,182	8,610	5,490					3,200	19,000					21,633		
Gila and small lost river basins	71,138	56,838								14,300							
Great basin	216,872		47,240		3,420				102,220			18,950			43,548		1,494
Sacramento and San Joaquin	63,675		63,020									655					
South coast, California	21,740		21,740														
North coast, California	17,750		17,750														
Southwest Oregon[j]	8,880											8,880					
Snake	108,680				73,500				5,280			17,950				6,682	5,268
Columbia in Montana, Idaho, and Washington[k]	59,040				7,880		25,000									26,160	
Columbia in Oregon[k]	24,093											24,093					

---

[a] West of the 100th meridian.

[b] Not including fifteen western counties.

[c] West of the 100th meridian and with part of Oklahoma.

[d] Not including twenty-one western counties.

[e] 13,315 square miles in Canada to be added.

With various streams west of 100th meridian, including Mouse, Little Missouri, Cheyenne, White, Niobrara, etc.

[g] North Platte, in Colorado, 2,025 square miles; South Platte, in Colorado, 20,205 square miles.

Including Pecos and all drainage in Texas west of 100th meridian.

Including all of Colorado river drainage in Utah, Arizona, and Colorado, excepting Green, Grand, and Gila basins.

[j] Coast drainage, mainly of Klamath river.

[k] Excepting Snake river drainage.

basins in this and preceding reports are taken in this general order wherever applicable, and from the east toward the west, as shown in the table. In this report the drainage basin of the Missouri, Yellowstone and Platte will be described.

MISSOURI RIVER BASIN.

LOCATION AND AREA.

The Missouri basin, as the term is used in reports concerning the arid region, usually includes the area tributary to the river of that name above the junction of the Yellowstone. As a matter of fact, the drainage basins of the Yellowstone, Little Missouri, Cheyenne, Platte, and other rivers form parts of the great basin of the Missouri river, but since each of these streams flows nearly to or beyond the limits of the arid region before uniting their waters in this great drainage system, it is more convenient to consider them as independent basins and at the same time to apply the name "Missouri" to the head water catchment area of that stream.

The total area of this basin is 95,093 square miles, of which 13,315 square miles, or 14 per cent, is within the Dominion of Canada, leaving 81,778 square miles, all in the state of Montana, with the exception of a few square miles in the Yellowstone National park. In this discussion of the water supply and the condition of irrigation reference is made only to the portion of the basin in Montana, few facts being available concerning the part in Canada. The boundaries of Montana have been laid out in such a manner that they include not only the greater part of the Missouri basin, but also in the southeast a portion of the Yellowstone basin, and on the west a large part of Clarke fork of the Columbia. The state line west of the Yellowstone National park follows for a portion of its course the rim of the basin, but with this single exception it has been located with reference to arbitrary lines rather than with regard to natural divisions.

The drainage basin of the Missouri, as shown by Pl. CVIII, is bounded on the west and southwest by the main range of the Rocky mountains, which forms the continental divide, separating the waters of the Missouri from those of the Columbia. On the southwest, where this divide forms the state line between Montana and Idaho, it separates the basin from the head waters of Snake river, or, as it was formerly known, Lewis fork of the Columbia. Further to the north, beyond the point where the Bitterroot mountains separate from the Rockies, these latter form the watershed between the Missouri and Clarke fork of the Columbia. Thus the Missouri basin is bounded on the south by the Yellowstone, a part of which is in Montana, on the southwest by the Snake basin in the state of Idaho, and on the west by Clarke fork in Montana.

ELEVATION AND TOPOGRAPHY.

The basin as a whole slopes toward the north and east, the highest ground, as shown by Pl. CVIII, being in the southwestern corner and along the western edge. The waters flow, therefore, in a general northerly and easterly course, leaving the basin not far from the northeastern corner. The rim of the basin is sharply defined in the higher portion, but in the eastern half, where the divides are low and rolling, the watershed is formed by prairie country, and therefore must be arbitrarily designated.

By means of the contours given on Pl. CVIII an estimate has been prepared of the area of the basin at various elevations. From an inspection of this table, given below, it is apparent that over one-half of the basin is at an elevation below 4,000 feet. In fact, the altitude is far less than it is popularly supposed to be.

	Square miles.
Total area in Montana	81, 778
Area under 2,000 feet	618
Area from 2,000 to 3,000 feet	26, 068
Area from 3,000 to 4,000 feet	22, 317
Area from 4,000 to 5,000 feet	13, 314
Area from 5,000 to 7,000 feet	13, 218
Area over 7,000 feet	6, 243

LAND CLASSIFICATION.

The small map on Pl. CVIII shows not only the general elevation of various parts of the basin, but, by means of the color, the general character of the lands within this area. Three general divisions have been made based upon the size or kind of the vegetation as determined by climate and altitude. The darkest shade indicates in a broad way the relative location of the forests or timber land, while the lighter green shows the area covered to a greater or less extent by scattered trees, suitable for firewood, occasionally furnishing material for purposes of fencing. The remainder of the basin, colored a light brown, supports a scanty vegetation, and, for the most part, may be considered as pasture land, including under this designation vast tracts whose soil is arable, and which, with an abundant water supply, would produce large crops.

Dividing the total area of the Missouri basin in Montana, viz, 81,728 square miles, into these three classes, it has been found that there are in arable or pasture land, approximately, 64,398 square miles, in land more or less covered with scattering firewood 10,640 square miles, leaving for the timbered land 6,740 square miles. These designations are largely arbitrary, for there is, unquestionably, good pasturage within the areas designated as being covered with timber or firewood, and, on the other hand, there are trees and shrubs of value to the farmer scattered along all of the principal streams in the eastern end of the State. There is little, if any, agricultural land within the areas covered in whole or part by trees, most of this being rough broken land or high mountains.

The arable and pasture lands shown on the map include the localities where agriculture is carried on, or where the soil is such that it could be developed. Unfortunately, however, as shown by the character of the vegetation, the rainfall is deficient and farming can not be successful without the artificial application of water. It has been found that in the census year ending May 31, 1890, crops were raised by irrigation upon 234,036 acres, or 365·7 square miles. This is only 0·57 per cent of the total area designated above as arable or pasture lands. The localities at which irrigation was carried on in the census year are shown by the dark spots on the map, Pl. CVIII.

Besides the irrigated portions of the arable or pasture lands, there are along the rivers many thousands of acres which by a careful utilization of the water supply can be brought under cultivation. The extent to which agriculture can be developed is, however, dependent wholly upon the thoroughness of the conservation of the flood waters and upon the degree to which the large rivers are utilized. The area irrigable, while governed somewhat by the topography, is controlled by the manner in which the water supply is employed. It is not possible, therefore, to make any rigid distinction between the irrigable lands and the arable or pasture lands, but on the small map the attempt is made to show by a darker shade the relative area and location of the lands which, under the best circumstances, can possibly be reclaimed by irrigation. The area thus colored aggregates in round numbers 1,000,000 acres, or 1,562 square miles.

EXTENT OF IRRIGATION.

The acreage irrigated in the Missouri basin, as above stated, aggregated 234,036 acres. This includes chiefly the area from which crops were obtained during the census year. The areas colored dark green on the small map are found mainly in the western and southern part of the basin near the points where the smaller tributaries issue from the mountains and flow out into the first open valleys. Agriculture by means of irrigation has already developed to such an extent that all of the streams which can be readily diverted, by one or two farmers or a number of neighbors acting in partnership, have been utilized nearly to their full extent during the summer season, and there remains little water unappropriated except that which flows during the spring floods.

While on the one hand the demand for water has already exceeded the supply along the upper valleys of the Missouri, further down, on the main river, there is a large amount flowing at all times of the year. Unfortunately, however, it is extremely difficult, if not impossible, to bring this water out upon the vast extent of arable land, owing to the steepness of the banks and the comparatively slight fall of the stream. There is thus a striking contrast between the condition of affairs in the eastern and western ends of the basin. In the latter locality are small streams with steep slopes flowing through comparatively narrow valleys, the water being widely distributed in the innumerable creeks, while in eastern Montana the water supply is all concentrated in the main rivers and the arable lands lie in great blocks embracing thousands of square miles.

The population is located mainly in the southwestern portion of the basin in the valleys among the mountains. This is due to the fact that the principal industry is mining, carried on in the canyons or gulches and among the crystalline rocks which contain the precious metals. If, however, the only industry were agriculture, this portion of the basin would still be the most prosperous and thickly settled, from the fact that the small streams in the mountains are widely distributed and the waters can be readily brought under control by the efforts of individuals or of companies. There is one peculiarity of the topography of this part of the basin which should be mentioned, namely, the bench lands which are found in each valley between the foothills and the narrow bottoms along the streams. These bench lands, although sometimes having gravel upon the surface, are usually very fertile, and as a rule surpass in excellence the lower lands along the bottoms of the valleys. They are usually cut by deep, narrow ravines, or coulees, as they are locally known, formed by the action of tributaries entering the main stream.

These bench lands are remnants of the beds deposited in former times from lake waters before the rivers had cut their present outlets. The streams leaving each valley pass through narrow canyons eroded by the flowing waters. Before these canyons were cut, the waters being held back, the material washed from the mountain was deposited, partially filling the deep basins. Gradually, however, the escaping water wore down the outlets until the bottoms of these lakes were laid bare, and continuing its downward course each stream cut trenches in the lake bottoms, in which the streams now flow. Thus each important stream in the western end of the basin flows at some distance below the general level of the bench lands, and its waters can be diverted with ease only upon the narrow flood plain. The principal problem presented to the irrigation engineer in this part of Montana is that of taking the water from the larger streams out upon these rich lands. The matter is complicated by the fact that they are deeply cut by the coulees traversing them at short distances, and also by the condition of development of irrigation, viz, the fact that many of the improvements made at present stand in the way of more comprehensive schemes.

WATER MEASUREMENTS.

The localities at which stream measurements have been made by this survey and the results obtained have been described in previous annual reports of the irrigation survey.[1] Some additional data have been obtained since the preparation of the last report and are presented herewith, together with a brief resume of the materials available for study of the fluctuations of water supply.

The three rivers, the Gallatin, Madison, and Jefferson, which unite to form the Missouri, have been measured at different times by the Geological Survey and by the Missouri River Commission. Continuous records of discharge have been computed for the Gallatin above Gallatin valley, and for the Madison near Red Bluff, while in the Jefferson basin Redrock creek alone has been observed for a series of months. A few measurements have been made on the Jefferson near Willow creek, that on August 19, 1889, giving a discharge of 202 second-feet, and on October 15, 1889, near Three Forks, 333 second-feet. Single measurements have also been made of some of the streams tributary to the Jefferson, viz, Ruby creek, Blacktail Deer creek, also Beaverhead and Bighole rivers, as noted in the following pages.

Several measurements have been made of the Madison near its mouth, that on August 17, 1889, at Blacks giving a discharge of 1,104 second-feet, and that of October 14, 1889, at Three Forks 1,191 second-feet. Considerable difficulty has been found in obtaining the discharges of the three rivers near their junction, on account of the fact that they divide into a number of channels and the height of the water in one stream affects the others for a considerable distance above.

Below the point at which the Gallatin, Madison, and Jefferson rivers unite a number of measurements have been made, showing that the discharge, as obtained by gaugings, has varied from about 2,500 second-feet up to over 8,500 second-feet. The seasonal fluctuations undoubtedly cause a variation both below and above these figures.

Besides the gauging stations of the Geological Survey at Toston, Canyon Ferry and Craig, described in former reports, records of the height of the water have been kept by the Missouri River Commission at a number of places, as shown by the following list, which includes all known data.

At Gallaher's Ferry, about 200 yards above the mouth of the Gallatin river, the height of the river has been recorded from August to November, 1890.

At Gallatin, Montana, records of river height have been kept from July to December, 1890. A measurement made at this point on August 6, 1890, gave a discharge of 2,640 second-feet. (In the Twelth Ann. Rept., pt. 2, p. 237, this is erroneously given as 2,460 second-feet.)

---

[1] United States Geological Survey, Eleventh Ann. Rept., pt. 2, 1889-'90, Washington, 1891, pp. 38-43, 93-94, 107; also Twelfth Ann. Rept., pt. 2, 1890-'91, pp. 236-238, 346-347.

At Toston, about 30 miles below Three Forks, the Geological Survey made six measurements from April 8 to July 26, 1890, the results being shown on page 42 of the second annual report on irrigation. The Missouri River Commission kept records of height from August 16, 1890, to February 28, 1891. The elevation of low water of 1890 at this place was about 3,879 feet.

At Townsend, 43 miles more or less below Three Forks, a permanent gauge was established October 1, 1891, by the Missouri River Commission.

At Canyon Ferry, about 18 miles from Helena, gaugings were made by the Geological Survey, giving the discharge for September, October, and November, 1889. A measurement made on September 18, 1890, by the Missouri River Commission near Canyon Ferry gave a discharge of 2,682 second-feet. The elevation of low water was in 1890 approximately 3,629 feet.

At French Bar, 71 miles below Three Forks, the discharge, as measured by T. P. Roberts on July 31, 1872, was 10,000 second-feet.

At Stubbs Ferry, which is given as being 73 miles from Three Forks a gauging was made in 1882 by the Missouri River Commission, showing a discharge of 3,770 second-feet. The records of river height have been kept from July, 1890, to January 17, 1891.

At Craig, a locality above the mouth of the Dearborn river, a gauging station was established by the Geological Survey and continued in operation through 1891. The elevation of low water of 1890, as determined by levelings made by the Missouri River Commission, was about 3,629 feet.

At Great Falls, Montana, records of river height were kept from September to December, 1890, by the Missouri River Commission, and possibly have been continued by the water-power company at that place.

At Fort Benton gaugings have been kept with more or less regularity from 1873 to 1876 and from 1881 to 1890. In August of this latter year a permanent station was established, taking as zero the low water of 1889. The daily gauge height from 1873 to 1876 has been published in lithographed form by Prof. Thomas Russell, of the Weather Bureau.[1]

PRECIPITATION.

Measurements of the amount of precipitation have been made at a number of points within this basin by the Signal Service of the U. S. Army, some of the records being continued for over fifteen years. The results of these measurements show that the rainfall, as measured at the various stations, varies from 10 to 20 inches, the average being about 15 inches, the greater part occurring in the months of May and June. The following list gives the names and location of the more important of these stations, with the length of time during which observations were made, and the mean annual rainfall as derived from records furnished by the Signal Service.

---

[1] Stages of the Mississippi and of its principal tributaries, 1860 to 1889, pt. 2, pp. 217-220.

Locality.	Length of record.	Depth of rainfall.
	Years.	*Inches.*
Fort Ellis, near Bozeman	15	19·6
Virginia, Madison county	9	16·0
Helena, Lewis and Clarke county	11	14·3
Fort Logan, head waters of Smith river	8	14·4
Piegan, head waters of Marias river	2	21·2
Fort Shaw, on Sun river	17	10·2
Fort Benton, mouth of Teton river	16	13·3
Fort Assiniboine, on Milk river	9	15·0
Fort Maginnis, near Judith mountains	7	16·6
Galpin, near mouth of Milk river	1	6·7
Poplar river	7	10·5
Fort Buford, mouth of Yellowstone	23	12·3

These localities are mainly in the valleys or on the plains, and therefore the results of the measurements do not represent the rainfall and snowfall upon the high mountains, which undoubtedly is considerably greater. It is safe to assume that the precipitation upon the summits is at least from 20 to 30 inches, and upon the valley lands of the western part of the Missouri basin at from 15 to 20 inches. In the eastern end of the basin, however, as shown by the measurements at Poplar river and Fort Buford, the rainfall rarely amounts to over 15 inches, ranging usually from 10 to 12 inches in depth.

The amount of rain falling in any one year may vary widely from the averages given in this statement, which nevertheless serve to indicate in a general way the distribution of precipitation over the basin. The variation from year to year is exceedingly irregular, but comparing one year with another, it appears from the records that there was a general decrease during the latter part of the decade, the depth of rainfall in 1889 and 1890 being at most stations below the average.

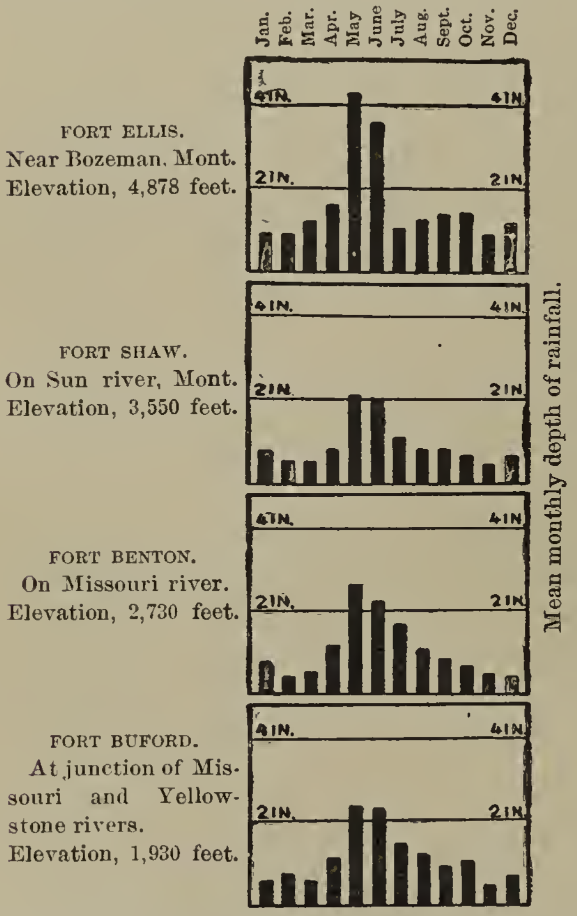


FIG. 52.—Diagram of mean monthly rainfall at four stations in the Missouri basin.

The distribution of the precipitation by months is shown graphically on Fig. 52, the results at four stations having the longest record being selected. These averages, although obtained from widely separated localities, have a similar appearance in that the greatest precipitation is in the month of May, followed by a slight decrease in June. During the remaining months of the year, however, there is a decided range in the proportion of rain falling, in the case of Fort Benton, for example, there being a gradual decrease to the end of the year, while at other stations there is great irregularity.

The distribution of rain throughout the year is shown by the following table, which gives the average precipitation per month as obtained from the stations named on page 40, and also gives the percentage of the amount for the year:

	Inches.	Per cent.
January	0·81	6·1
February	0·65	4·9
March	0·82	6·1
April	1·02	7·7
May	2·51	18·8
June	2·10	15·7
July	1·29	9·7
August	1·03	7·7
September	1·03	7·7
October	0·85	6·4
November	0·58	4·3
December	0·66	4·9
Total	13·35	100·0

This peculiar distribution of the rainfall is in itself favorable to agriculture, for, taking the months of May, June, and July as the principal part of the growing season, it appears that in an ordinary year over one-third of the rain falls during these months, and thus, although the rainfall is as a whole deficient, yet what there is comes at the time when it will do the most good.

With this brief summary of the principal facts concerning the basin as a whole, a more detailed description of the water supply in each sub-basin is given in the following pages, taking these in order from the head waters down, beginning with the Gallatin, Madison, and Jefferson, and preserving in general the geographic order.

GALLATIN RIVER.

The Gallatin river rises in the high mountains in the northwestern corner of the Yellowstone National park and in the ranges north of this. The river flows in a general northerly course through a succession of narrow valleys and canyons for a distance of about 50 miles from its head waters, finally entering the Gallatin valley, one of the finest agricultural areas in Montana, or even in any of the western states. At the lower end of this valley the stream receives the waters of the East Gallatin, which drains the short range of the same name. The small tributaries coming from these mountains unite near the base and flow in a general northwesterly direction along the eastern side of the Gallatin valley. At a distance of about 10 miles below the mouth of the East Gallatin the main stream enters the Missouri.

The water supply of the Gallatin valley is peculiarly favorable to irrigation, and this, with the rich soil and temperate climate, has rendered possible a high state of agricultural development. On the eastern side of the valley is Bozeman, and a number of smaller towns are scattered about. The small streams coming in from the east and south have enabled irrigators to bring under cultivation large areas of crops at moderate expenditure of labor, and as these convenient sources of supply have been utilized in turn and population increased, they have rendered possible the construction of large systems of irrigation deriving water from the principal river, the West Gallatin. Thus by the distribution of small streams irrigation has grown rapidly and without interfering greatly with the thorough utilization of the magnificent water supply.

As has been previously stated, the amount of water entering the Gallatin valley by means of the main stream has been measured at a station below the mouth of Spanish creek near where the river leaves the canyon. The total area drained is 850 square miles, most of this being high, steep, mountain areas heavily covered with timber. The run-off, therefore, is unusually large, being from 13 to 14 inches in depth over the whole basin; that is to say, if the water flowing from this drainage area during one year were put back upon a plain of the same size it would cover it to the depth of 13 or 14 inches. The average rainfall is not known, but probably can not be much less than 30 inches. If this be the case the run-off represents nearly one-half of the precipitation upon the catchment area.

The discharge of the stream has varied from 320 to 6,800 second-feet, the average for three years being over 950 second-feet. This is equivalent to an average discharge of 1·12 second-foot for each square mile drained, the amount varying at different times of the year from about four-tenths of a second-foot up to 8 second-feet per square mile. This rate of run-off is probably greater than that from the East Gallatin range, from the fact that the topography in the latter case is less favorable to rapid discharge of the precipitation.

In Fig. 53 is given the daily discharge of the West Gallatin river at the gauging station previously mentioned from May, 1891, to the middle of July, 1892, with the exception of the month of April, 1892. As will be seen by the inspection of the diagram, the flood discharge of 1892 was far greater than that of 1891, this latter being represented by the lighter line. The diagram is not sufficiently high to show the maximum point, 6,800 second-feet, reached in June, 1892. Comparison should be made with the diagram on Pl. LX, in the Twelfth Annual Report, giving the discharge at this station from 1889 to 1891.[1] On this plate the discharge for 1891 represented by a dotted line, is seen to be somewhat less than the discharge for 1890, this latter, however, being decidedly lower than the quantity shown on Fig. 53. This difference is best exhibited by the table of mean monthly and annual discharge shown on page 98, where the mean annual discharges for 1890, 1891, and 1892 are respectively 871, 880, and 1,123 second-feet. The rapid fluctuations shown on the diagram as taking place during time of high water are undoubtedly due largely to changes of temperature.

---

[1] U. S. Geol. Survey, Twelfth Ann. Rept., pt. 2, Irrigation, p. 228.

Taking the mean annual discharge of the West Gallatin as 950 second-feet, this, with a water duty of 100 acres to the second-foot, should irrigate 95,000 acres. It would be necessary, however, to store a large part of this water in order to make it available. By complete systems of storage and careful use of the water this duty could be somewhat increased, rendering it possible to cover at least 100,000 acres, an amount which would probably embrace the greater part of the irrigable land along the stream.

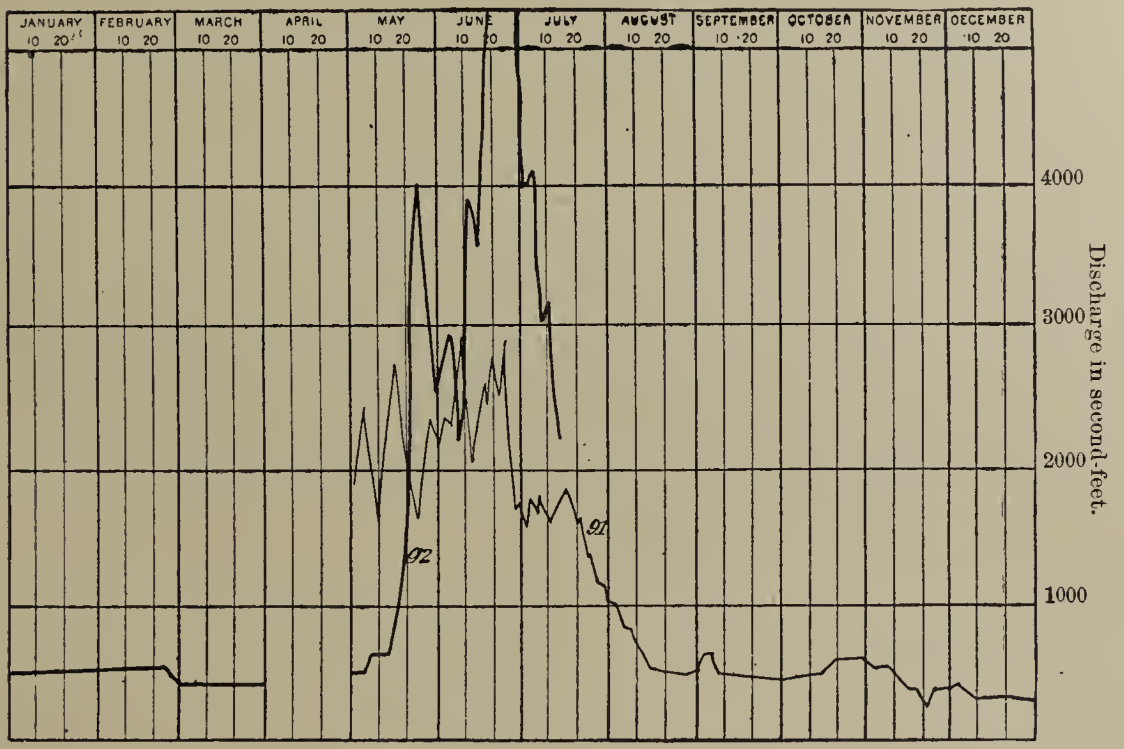


FIG. 53.—Diagram of daily discharge of West Gallatin river below Spanish creek, Mont., 1891-'92.

The Gallatin valley, as well as the great part of the catchment area of the river, is included within Gallatin county, Montana, the lines of this county extending in a westerly direction to the Jefferson river and thus including the valleys at the mouth of Madison river and Willow creek. The statistics of the Eleventh census show that in this county there were 434 irrigated farms, upon which 46,901 acres of crops were raised, the average size of the irrigated holding being thus 108 acres. These farms were mainly along the eastern edge of the Gallatin valley in the vicinity of Bozeman and northwesterly from this locality along the foothills.

The altitude of Gallatin valley may be taken in round numbers as from 4,000 to 5,000 feet above sea level. At Bozeman, on its eastern side, the railroad track is at an elevation of 4,754 feet, while at Gallatin, at the lower end of the valley near the Missouri river, the elevation of the track is 4,032 feet. The fall is thus sufficiently great at all points to render possible the diversion of water from the streams upon nearly all of the bench lands, so that there are few limitations of this kind to the development of irrigation systems.

The water from the small streams which make up the East Gallatin has been appropriated and utilized by farmers, the only exception being in the case of waters during the spring floods. Toward the end of summer the streams become very small and there is not a sufficient supply to fill the demands made upon them. During the drought of 1889 and 1890 there was not sufficient water to irrigate all of the land under cultivation, and the necessity of storing some of the surplus water of spring became more than ever apparent. One or two enterprises of this character have been begun, but as yet have not come into active operation. There have been many complaints of injustice on the part of various individuals claiming water from the small streams, some of the older settlers asserting that they have been deprived of what was rightfully theirs, and, on the other hand, many of the later comers assert that the waters have not been fairly divided.

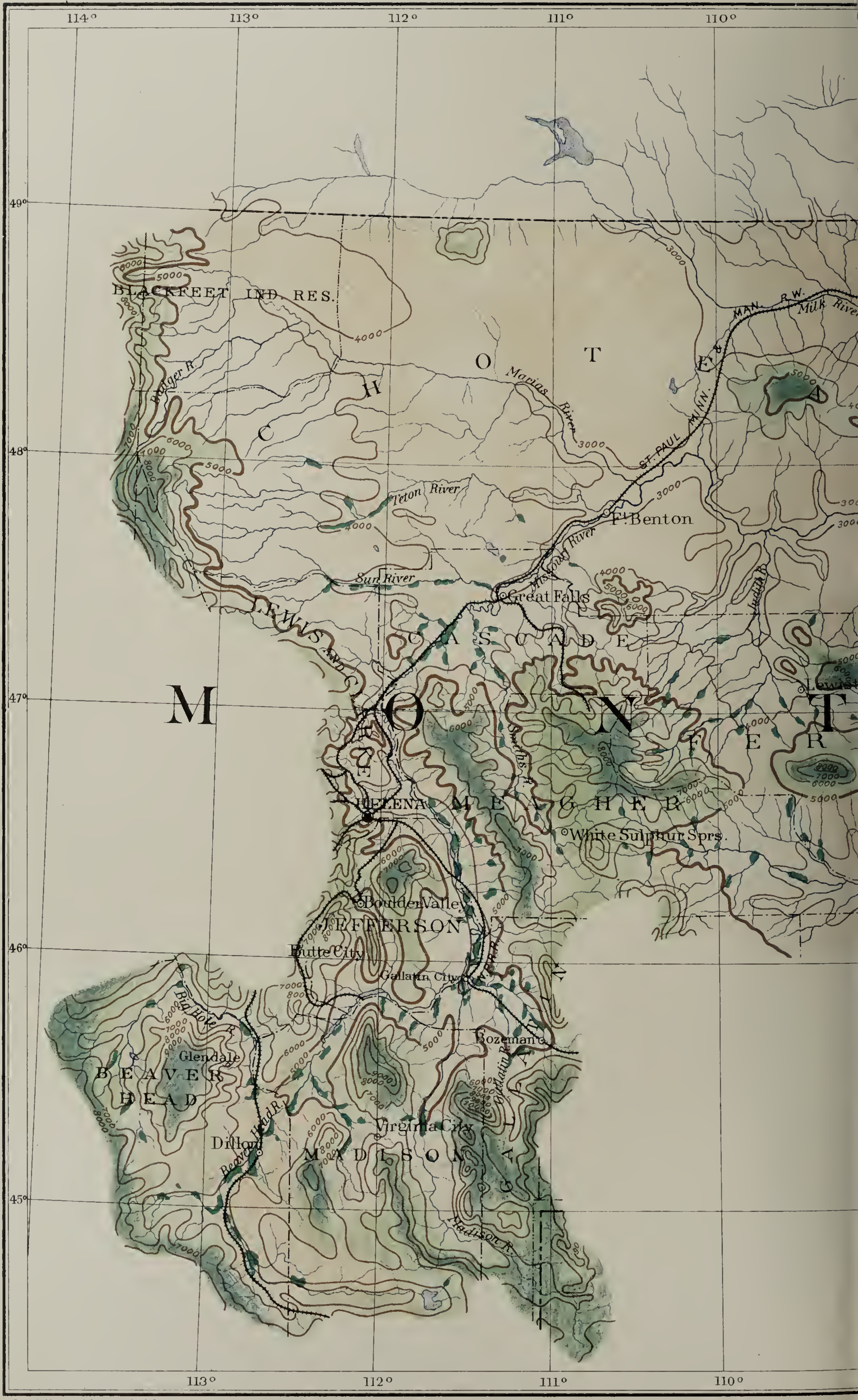
The principal irrigating streams, taken in order from the West Gallatin easterly around the valley, are given below, together with the average amount of water flowing during the irrigating season as estimated by a resident of Bozeman:

	Second-feet.		Second-feet.
Wilson creek	16	Bridger creek	30
Bear creek	20	Little Cottonwood creek	12
Cottonwood creek	30	Spring creek	20
Middle creek	50	Reese creek	20
Bozeman creek	24	Dry creek	16
Reservation creek	24		

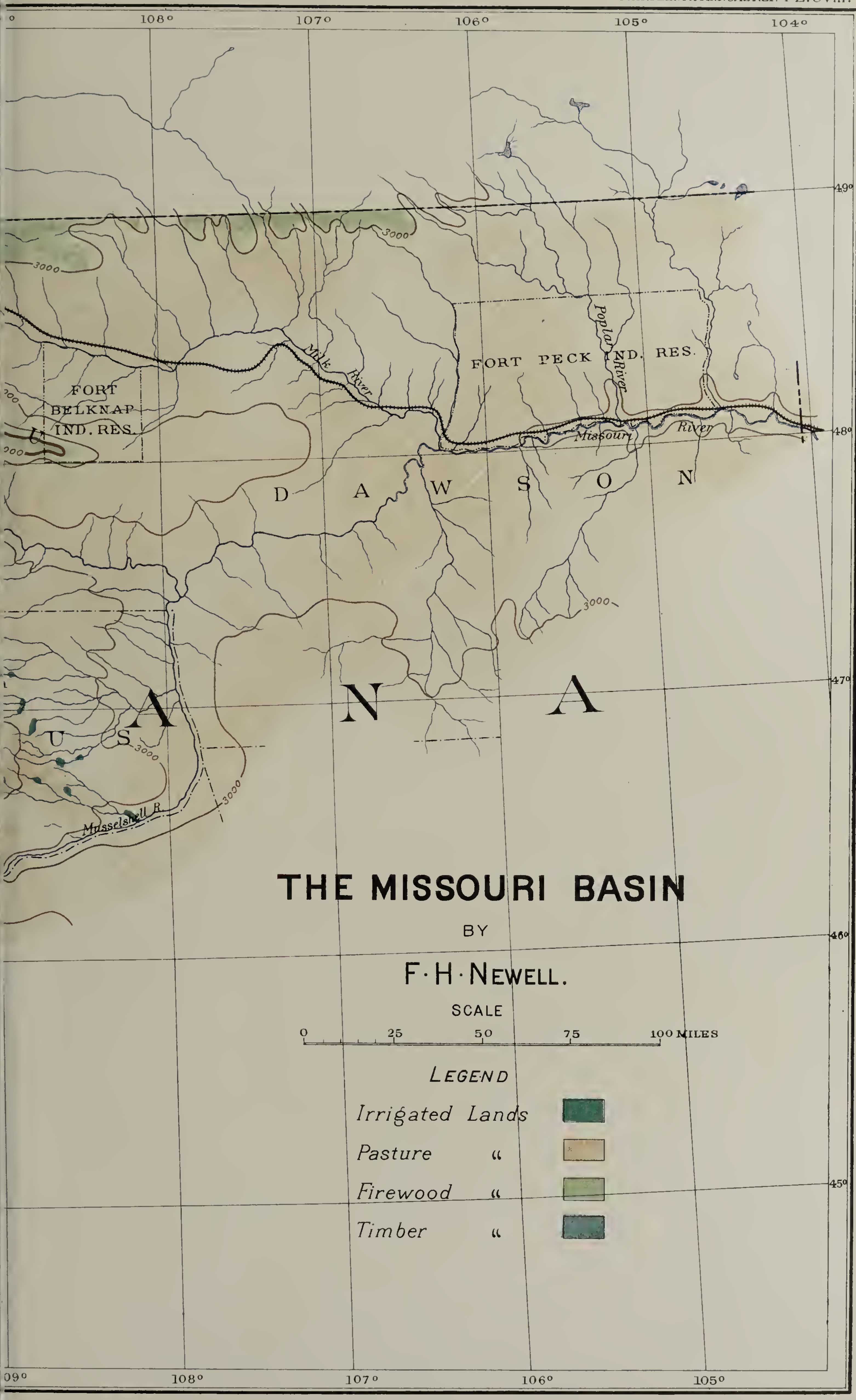
Bozeman, Reservation, and Bridger creeks unite to form the East Gallatin river. The streams below this, namely, Little Cottonwood, Spring, Reese, and Dry, seldom reach the river except during the spring floods. The water supply from the streams named above, together with that taken from the West Gallatin river, aggregates 522 second-feet, assuming that the amount contributed by the canals from this latter river is as follows: West Gallatin and Bozeman canal, 100 second-feet; Excelsior canal, 100 second-feet, and Middle Creek ditch, 60 second-feet.

Near the edges of the valley, among the foothills, a few crops can occasionally be raised without irrigation. For example, winter wheat in years of abundant snowfall yields largely. Also on the low grounds along the river, where the fall is slight, are areas where irrigation is not essential, but these are comparatively small, and it may be said

U.S.GEOLOGICAL SURVEY.



Geo.S Harris & Sons Lith Phila



THE MISSOURI BASIN

BY

F·H·NEWELL.

that the value of the lands of the valley rests immediately upon the amount of water supply and the thoroughness with which this is utilized.

While there has been a considerable development of agriculture by means of the waters of the smaller streams, the greatest increase of area tilled since the census year comes through the construction and extension of a few large canals taking water from the West Gallatin river. These head in or near the mouth of the canyon and take the water out upon both sides of the river, covering on the west side at least a large portion of the bench lands. There are two canals on the east side, the Bozeman and West Gallatin canal and the Excelsior, these running toward the northeast in the direction of Bozeman and approximately parallel to each other. The latter was built by an association of farmers in the attempt to secure water at less rates than those offered by the first-named company.

The canal of the West Gallatin Irrigation Company heads on the west side of the river a little over 3 miles above Salesville, and after following the stream for several miles turns off to the west, passing through a ridge or spur by means of a tunnel and then out upon the bench lands lying between the Gallatin and Madison rivers. The surface is greatly eroded by small streams which flow in spring from the mountains, and many of these gulches are crossed by flumes. The total length of this canal as completed during 1891 was 23 miles, and the average bottom width 14 feet. It can be made to cover approximately 60,000 acres, the greater part if not all of which is arable.

Besides the three large canals mentioned above there are many ditches taking water from both sides of the stream and carrying it out upon the land in the lower end of the valley and over toward Three Forks. Some of the best farms, if not the finest in the whole state, are in this vicinity, and, as shown by the irrigators, the crops which have been produced can not be excelled by any in Montana for quantity as well as quality.

Settlement began in the Gallatin valley, according to statement of a correspondent, in 1863, crops of grain and vegetables being raised in the following year. Since that time there has been a steady increase year by year in the acreage under cultivation by irrigation, so that now a great part of the valley is covered by a network of ditches. Irrigation is regarded by all as indispensable, although as previously stated, there are a few farms lying near the mountains where it is apparent that the late spring and early summer rains fall more copiously and later in the season than they do upon the lower lands, and it is here that the winter wheat can be relied upon with a reasonable degree of confidence to produce a remunerative crop. By irrigation, however, the yield could be greatly increased, and it is only because this is impracticable that the so-called dry farming is attempted.

On the lower, moist grounds along the rivers or near the swamps in the valley large crops have been raised from the time of the settlement of the valley without the soil apparently losing its fertility, but, unfortunately, the alkaline salts tend to develop in such localities, destroying the value of the land unless great care is used to neutralize the effect of these minerals. It is stated that land in this valley has been producing wheat, oats, and barley for over twenty years without signs of deterioration, and now produces from 35 to 45 bushels of wheat per acre without artificial fertilizers.

Until the drought of 1889 the farmers deemed it sufficient to provide irrigation for only a small portion of their farms, relying upon seepage to furnish sufficient moisture for other parts. The experience of that year, however, showed the necessity of having a reserve supply of water and of providing ditches to use in time of unusual drought. Without an ample supply and a thorough system of distributing the amount available irrigation, in the words of one who has had experience, " becomes a constant source of trouble and worry. There is more litigation and bad feeling among farmers over water rights and the use of water than in all other affairs combined."

MADISON RIVER.

The Madison river rises in the Yellowstone National park southeast of the head waters of the West Gallatin, a great part of the water coming from the hot springs and geysers of Firehole river and other streams in the park. It flows in a general westerly and northwesterly direction for about 40 miles through canyons, then turns toward the north, and soon after enters Madison valley, a long narrow opening bounded at both ends by canyons through which the river flows. The catchment area of this stream above Madison valley is in most respects similar to that of the West Gallatin, with the possible exception that the slopes may be a trifle less steep and the water delivered with a little less rapidity to the stream.

Below Madison valley the river continues in the lower canyon for over 10 miles before the walls again fall back. The gauging station of the Geological Survey is in this canyon at a point a short distance below the mouth of Hot Spring creek. The measurements obtained at this place represent therefore the amount of water flowing out of Madison valley, a comparatively small quantity being added during the passage of the river through the canyon.

Madison valley lies at a general altitude of from 4,800 to 5,000 feet. It is over 30 miles in length from north to south, and upwards of 8 miles in width at about its center. There is no railroad in the valley, the only means of transportation being by wagon road across the mountains. In spite of this fact, however, agriculture has developed to a comparatively large extent owing to the ready market for supplies at mining towns in that part of the state.

The water used for irrigation in Madison valley is taken almost exclusively from the creeks which come from the mountains on both sides. These on the east rise to heights of over 10,000 feet, and the streams draining their slopes carry a considerable amount of water throughout the year. The main river, traversing the valley from south to north, is little used on account of the fact that small ditches can be built from the side streams to cover the arable lands at far less expense and by the exercise of less skill than from the river.

As in the case of the other valleys of Montana, the droughts of 1889 and 1890 impressed upon the farmers the fact that irrigation works must be so planned and constructed that they will receive an ample supply under unusual circumstances. In these years far more water than usual was required, and in 1890 much of the land had to be irrigated in order to plow it, or to enable the crops to start. In ordinary seasons no irrigation is necessary in this valley for the first crop of lucern, and it is customary to give only one watering to small grain. In these latter years of drought there was no decided loss of crops, but the yield was not as large as usual owing to the scarcity of water at critical times.

This valley is in the east end of Madison county, which extends from the summits of Madison range westerly to Jefferson river. The county thus includes several localities besides Madison valley in which irrigation is practiced. According to the census the total number of irrigators in the county was 345 and the acreage of crop irrigated 36,819, giving an average of 107 acres per farm. It is evident from the average size of the crop areas that the methods of applying water must be comparatively crude and that it is used with little care and personal attention. The irrigating ditches are small and are owned usually by a few farmers, there being but one or two systems of notable size.

It is probable that the Madison river can be diverted by means of large canals, one on each side of the valley, and by this means bring under irrigation all of the lowland and even a portion of the benches, and that by a well planned system the higher benches can be cultivated by means of the water from the side streams. It will be necessary, however, to make careful surveys before the feasibility of such projects can be determined. In the north end of the valley near Meadow creek is a large area of arable land, the water supply for which is at present insufficient. This can undoubtedly be irrigated, however, in part at least by the construction of storage reservoirs on Meadow creek, as, for example, at North Meadow creek lake, where, it is stated, the water can readily be held. At present the farmers in this locality state that owing to scarcity of water they can not raise sufficient hay to carry the stock through the winter, and that there are heavy losses in consequence.

The gauging station of the Geological Survey, as noted in the second annual report, is below the mouth of Hot Spring creek, 4 miles from the town of Red Bluff, at Hayward bridge.[1] The results of the computations of discharge are shown in Fig. 54, which gives the daily discharge for 1891 and for the first half of 1892. This diagram should be compared with that on Pl. LXI, in the Twelfth Annual Report,[2] where is given diagrammatically the quantity of water in the river in 1890 and during the early months of 1891. Reference should also be made to the table of mean monthly and annual discharge on page 92 of the present report.

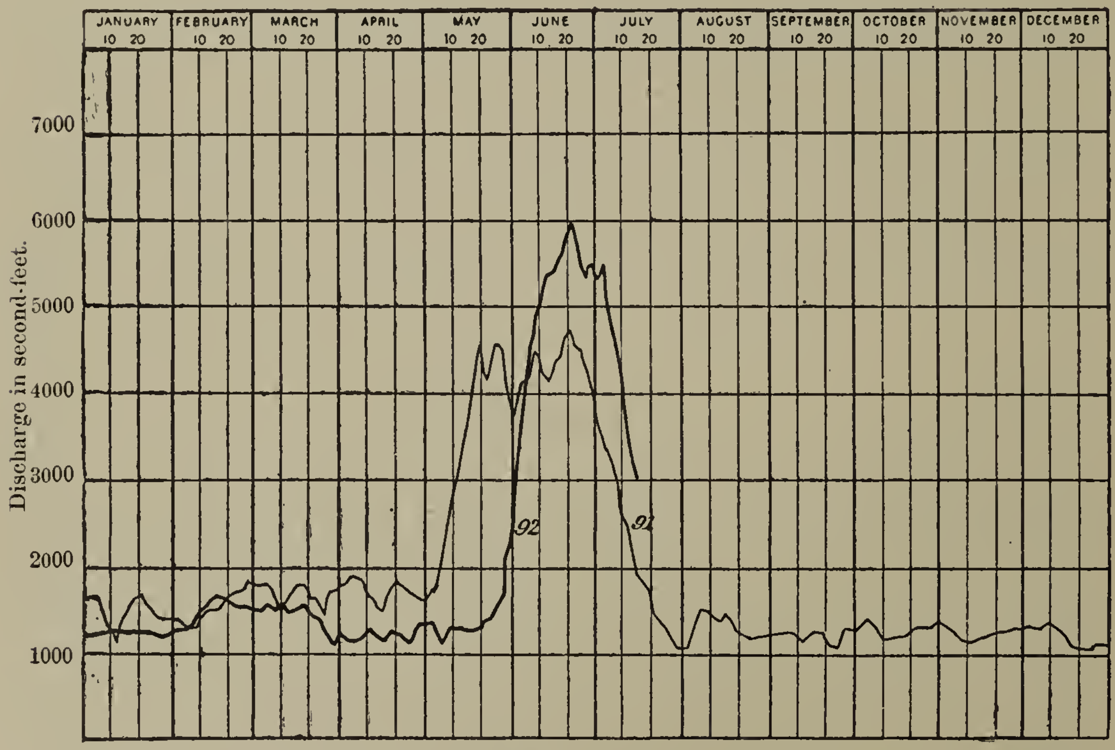


Fig. 54.—Diagram of daily discharge of Madison river near Red Bluff, Mont., 1891 and 1892.

About 6 miles below the gauging station the Madison river crosses the county line and enters Gallatin county, and a short distance beyond this point the valley widens, opening out into the western prolongation of Gallatin valley. Comparatively little irrigation is carried on along the river on account of the difficulty and expense of diverting water. From the topography of the country, however, it would appear that large canals can be built to carry water upon the bench lands upon each side. The practicability of such schemes can only be determined by survey. The amount of water available, as shown by the stream measurements, is large, the average for three years being over 1,900 second-feet. This, at a water duty of 100 acres to the second-foot, would irrigate 190,000 acres, an amount far greater than can probably be covered by canals. Thus the water supply along the Madison river if properly utilized will probably be far in excess of the demands made upon it.

---

[1] See U. S. Geol. Survey, Eleventh Ann. Rept., 1889-90, pt. 2, p. 40.

[2] U. S. Geol. Survey, Twelfth Ann. Rept., pt. 2, Irrigation, p. 230.

The bench land on the west side of the Madison river contains a body of arable land probably as good as any in the state. This land extends from Three Forks up the Madison river for 10 or 12 miles and west to Willow creek, a distance of nearly 8 miles. Little, if any, of this land is under cultivation, on account of the expense of constructing a canal. One-half of the land to be benefited is reported to belong to the Northern Pacific railroad, which owns alternate sections. At present there are only a few hay ranches along the stream, the owners being engaged in stock-raising. Wherever the ground is sufficiently moist a little hay is cut without irrigation, but away from the flood plains of the rivers nothing can be raised at present. The soil, however, is very rich, and although it now produces merely a stunted growth of bunchgrass, by irrigation upwards of 40 bushels or wheat and 60 of oats per acre can be raised.

JEFFERSON RIVER.

The drainage basin of the Jefferson lies west of that of the Madison and includes the area surrounded on the south and west by the great bend or loop in the continental divide or watershed. The drainage area of this stream is over four times as great as that of the Madison, but, in spite of this fact, the mean annual discharge of the stream is probably not as great, owing to the difference in character of topography and the lower elevation. The main stream is formed by the union of Bighole river, coming in from the west, and the Beaverhead from the south. From this point the river flows in a general northeasterly course for a distance of 60 miles to its junction with the Madison and Gallatin, forming the Missouri river.

Redrock creek, the head waters of Beaverhead river, rises in the mountains south of Madison valley and flows west, parallel to the continental divide, through a broad open valley, in which are numerous small lakes and marshes, furnishing excellent pasturage. This is known as Centennial valley. It is about 40 miles long and from 2 to 3 miles in width, and lies at an elevation of about 6,000 feet. Redrock creek, after flowing beyond the line between Madison and Beaverhead counties, turns toward the north and flows through an open though broken country, suitable principally for grazing. The bed of the stream frequently becomes nearly dry at various points in Beaverhead county during the latter part of summer, and it will be necessary to store some of the water in order to increase the acreage of irrigated crops.

A gauging station was established on April 9, 1890, at Redrock, a short distance above the mouth of Horse Prairie creek, and measurements were continued until October. The average discharge for the year is estimated to have been 148 second-feet. The daily discharge of Redrock creek for the time during which observations were made is shown in the twelfth annual report, part 2, Pl. LX, in connection with the diagram for the West Gallatin river. The drainage area is 1,330 square miles, and this amount of water would cover this area to a depth of 1½ inches. The mean annual run-off from this catchment area was a little over 0.1 of a second-foot per square mile. A measurement was made of Redrock creek at Alderdice, about 20 miles above Redrock, the discharge on September 6, 1890, being 10 second-feet.

Below Redrock station several important tributaries enter the stream, the principal of those from the west being Horse Prairie, Grasshopper, and Rattlesnake creeks, and from the east Blacktail Deer creek. The latter stream was measured on September 4, 1889, at Poindexter, the discharge being only 10 second-feet from a drainage area of 300 square miles. This amount may be considered as the waste or seepage water from the ditches above.

The Beaverhead river, formed by the union of the creeks named above, flows toward the northeast through an open country having an elevation of from 4,800 to 5,400 feet, the valley lands extending on each side up tributary streams. The water supply, especially in summer, is very scanty on account of the fact that the head waters of these streams are among comparatively low, broad mountains, from which the rain and snow water is not discharged with rapidity. In the higher valleys the various forage plants, with the exception of alfalfa, are raised, and also wheat, oats, and barley, the climate being in general too cold for corn and many of the common fruits.

In consequence of the scanty supply of water and the lack of efficient regulations governing the distribution of it, controversies are constantly arising concerning the use of the water, and these lead to almost endless litigation. It is impossible for the agricultural resources to be developed until the water supply is increased by storage and until a thorough system of water control is inaugurated, so that the irrigator may be reasonably sure of receiving a fair proportion of water each year.

In many of the upper valleys, as, for example, on Grasshopper creek, the settlers for nearly thirty years have raised nothing but hay along creek bottoms. They have not produced even the common garden vegetables, but many of them are convinced that if the lands were thoroughly cultivated and the water not allowed to run to waste, but stored and held for use during the summer, the production per acre could be increased threefold, and the water could be made to cover many times as much land as it does at present. It is stated that under present methods the full limit of farming has been reached, and that when a ranch is taken higher up on the river and irrigated some person further down the stream must stop farming for lack of water. One farmer states that when he bought his land he had an abundant supply, but as other persons brought under cultivation land higher and higher up on the river and its tributaries, he, with others, began to lose the usual supply, and as a result all parties are engaged in lawsuits.

Near Dillon a deep well has been drilled to a depth of 450 feet, at a cost of about $5,000, in the hopes of obtaining artesian water. There is especial need here for water for the farms already under cultivation, not to mention the thousands of acres that might be cultivated if water could be had. The farmers, as a rule, see the imperfection of the present methods of irrigation, but are unable to unite upon any practicable plan to remedy matters. The first settlers claim most, if not all, of the water during dry seasons, and the later comers do not see why they are not entitled to as much water as the others.

The Bighole, or, as it was formerly known, Wisdom river, rises in the mountain ranges northwest of the headwaters of Beaverhead river. It flows northerly through broad, open valleys, then turns to the east and southeast, describing roughly a half circle in a general way parallel to that formed by the continental divide. It is probable that this river carries a larger amount of water than does the Beaverhead, but, unfortunately, few measurements have been made. On September 8, 1889, the Bighole, as measured at Melrose, was discharging only 60 second-feet from a drainage area of 2,335 square miles. At about the same time, viz, September 9, the Beaverhead, at Dillon, where the drainage area is approximately 4,000 square miles, was discharging 75 second-feet.

When the upper valleys along this stream were first settled it was found that good hay grew in abundance along the river and on the small creek bottoms that were overflowed in spring and early summer. These lands were rapidly taken up, and for many years the inhabitants were successful in raising sufficient hay for their cattle without irrigation. In 1889, however, there was almost complete failure of crops on such land, but those persons who had taken water out upon the bench or high lands had a fairly good crop.

A short distance above the junction of the Beaverhead and Bighole rivers Ruby creek enters from the southeast, bringing water from the Jefferson range, Ruby range, and other mountains, the drainage basin of this river being included within Madison county. This stream is reported to flow continuously throughout the year, and the ditches depending upon it usually receive an amount of water sufficient for ordinary needs. In the case of many of the tributaries, however, the supply is less abundant, some of them becoming dry during summer. A measurement of Ruby creek was made at Laurin on September 4, 1889, and the discharge was found to be 90 second-feet from a drainage area of approximately 710 square miles.

There is complaint that the ditches are too small and that the loss by evaporation and seepage is enormous; also, that the construction has been so poor that the annual expense of maintenance is a serious matter to the irrigator. There is a great need not only here, but elsewhere in the basin, of storage reservoirs near the head of the river, and of more thorough systems of employing the water already available. It is stated that there is great wastage from lack of definite rules regarding the use of the water, some persons allowing it to run where it does no good, or neglecting to employ it properly in spring and fall. The ground also is not always properly prepared, and the losses through ignorance and carelessness are often greater than those through scarcity of supply.

Along the lower part of the Beaverhead many farms depend upon seepage and overflow, the only crop raised being hay. The cultivated lands lie higher and must be irrigated by means of ditches before anything can be produced, the only exception being in the case of certain soils which, in an unusually rainy season, retain sufficient moisture to support an inferior growth. In 1890, as well as in 1889, the Beaverhead was dry in certain places and it is probable that this condition of things will occur again and again, since more land is being brought under cultivation on the tributaries each year. The only apparent relief is from storage reservoirs. In a few instances alkali is reported to have developed on some of the lower lands to an extent sufficient to kill grass and other plants, resulting in partial or complete abandonment of these spots.

Below the junction of the Beaverhead and Bighole rivers the Jefferson receives a number of tributaries, the principal of these from the north being Pipestone, Whitetail Deer, and North Boulder creeks, these being in Jefferson county, and from the south Coal, Bell, South Boulder, and Willow creeks, these coming from the Jefferson range.

On North Boulder creek, as on many of the other streams, there is great scarcity of water, and as the settlers bring more and more land under cultivation the demand steadily increases. In this part of the state examples are furnished of the changes in industry, the first settlers being attracted by mining, and then to some extent taking up stock-raising. After awhile the stock ranges become overstocked, and during the dry seasons the grass has been almost destroyed. As a consequence the settlers have turned their attention more and more to agriculture, and the strife for water has become severe. It is asserted that there is not sufficient water along North Boulder creek for one acre out of ten of the tillable lands unless some is saved by storage. In the dry seasons of 1889 and 1890 this creek and the Little Boulder were very low, and even dry in places, and the floods, which generally wet the bottom lands in April and May, were too small to be of much benefit.

The drainage basin of Jefferson river includes all of Beaverhead county, the southern part of Silverbow county, the western part of Madison and the south end of Jefferson county. According to the census there were in Beaverhead county 294 irrigators and a total crop area of 42,606 acres irrigated, the average size of farm being 145 acres. In Silverbow county there were 75 irrigators and 5,968 acres irrigated, most of this undoubtedly being along the Bighole river or its tributaries. In Jefferson and Madison counties the acreage irrigated, as previously stated, lies partly in other basins.

MISSOURI VALLEY.

This name is commonly applied to the long, narrow valley lying for the most part on the east side of the Missouri river southeast of Helena. The river below Three Forks continues northerly for about 20 miles, principally in a gorge or canyon. At Toston the valley begins to widen, the river keeping its course near the hills on the western side, leaving broad bench and low lands on the east. The valley terminates near Canyon Ferry, a point 18 miles from Helena in a direction a little north of east. A large number of streams rising in the Belt mountains enter this valley from the east, furnishing a well distributed though small water supply.

Irrigation in the Missouri valley is carried on mainly by means of water from the tributaries, the water of the main river being used to a very small extent, if at all. This is due to the fact that ditches can be diverted from the side streams with far greater ease than from the river on account of their decided fall and the elevation of their beds relative to the lands to be irrigated. The water in these streams decreases rapidly in July and many of them become dry later in the season. In 1889 it is reported that not to exceed one-fourth of a crop was raised in the valley, and in many instances there was an entire failure owing to scarcity of water. In the following year the condition of affairs was a little better, but some farmers failed to obtain fair returns.

The quantity of water in the streams varies greatly with the character of the weather during the winter season. If the fall is dry and there is a large amount of snow during winter a large part of this saturates the ground, but, on the other hand, if the ground is frozen before snow comes it often melts and runs away without being of benefit. The farmers have become accustomed to estimating the probable amount of water available during the succeeding season and as far as possible regulate their crops in accordance with the probabilities.

The great need of this valley is of a large canal taking water from the Missouri river and bringing it out at an elevation sufficient to cover the thousands of acres of excellent land. Whether this is practicable can be determined only by thorough examination of the route of such a canal.[1] If this could be done then the water of the side streams could be used upon bench lands above the reach of the canal. As regards water supply there can be no question, for the amount in the river, as shown by measurements, is ample for all demands of this kind.

The amount of water in the Missouri river at the head of the valley is practically the same as that at the junction of the Gallatin, Madison, and Jefferson, since only a few small streams enter between these two places. The measurements of flowing water made in this part of the river have been previously mentioned on p. 39. The details of those made at Toston from April 8 to July 26, 1890, are given on page 42 of the second annual report.[1] According to these measurements the discharge at that time varied from 3,697 second-feet to 14,440. The measurements made by T. P. Roberts in 1872 are mentioned on p. 236 of the third annual report,[2] the result obtained by him in the latter part of July being 8,538 second-feet. On July 28, 1890, the discharge, as measured by the Missouri River Commission, was 2,863 second-feet, and on August 6, 1890, 2,640 second-feet.

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. 2, Irrigation, p. 114.

Besides the computations of discharge made for localities above the valley, others, as given on p. 39, were made for stations at the lower end of the valley, where the river again enters the canyons, viz, at Canyon Ferry, Stubbs Ferry, and localities in that vicinity. A comparison of the results obtained at these places, together with those from the gauging station at Craig, shows that at the time of greatest drought the river rarely falls below 2,000 second-feet, so that at all times there will be an ample supply in the river for use upon the irrigable lands. As previously stated, a permanent station has been established at Townsend by the Missouri River Commission, where records of the fluctuations of the height of the stream are being kept.

The quantity of water delivered by the streams coming from the Big Belt mountains is not known, but there is unquestionably an amount sufficiently large to fill during the spring numerous reservoirs among the foothills. By saving the surplus water in this way a larger acreage could be brought under cultivation in the Missouri valley, and it is possible that the greater part of the land could in time be irrigated should a large canal from the Missouri river prove impracticable. On the other hand, even with a canal of this character there would still remain elevated tracts on the bench lands to be supplied with water from storage.

The eastern side of Missouri valley is in the western end of Meagher county, the river forming the county line, while the land on the opposite bank of the stream is in Jefferson county. In this latter locality most of the farmers depend for irrigation mainly upon water from the Missouri river, taking it out during flood time. When the stream falls they can no longer bring the water out upon their ground and in summer the crops often are very scanty on account of the lack of moisture. The streams from the Jefferson range are less in number and carry a smaller amount of water than is the case of those from the Belt mountains in the east.

PRICKLY PEAR VALLEY.

Prickly Pear valley is northwest of Missouri valley, lying on the west side of the Missouri river and beginning nearly opposite the lower end of this latter valley. The Jefferson mountains are on the south and the continental divide with its spurs on the west and north. The city of Helena, the capital of Montana, is on the southwestern edge of the open land. The elevation of the valley is from 3,800 to 4,200 feet, the railroad at the city of Helena being 3,932 feet above sea level. The valley is nearly 12 miles wide and 20 miles long, but, although comparatively thickly settled, the water supply is deficient. Wherever water can be obtained, however, the land is thoroughly cultivated.

---

[1] U. S. Geol. Survey, Eleventh Ann. Rept., pt. II, irrigation, p. 42.

[2] Twelfth Ann. Rept. U. S. Geol. Survey, pt. 2, Irrigation, p. 236.

In the Prickly Pear valley there are thousands of acres of arable land which by irrigation would produce heavy crops. Unfortunately the Missouri river is at an elevation too low to be brought out upon any of this land, for, as previously stated, the elevation of low water at Toston is 3,879 feet and at Craig, 3,629. The only way of increasing the water supply, therefore, is by storing the spring floods. Occasionally there have been seasons in which there was sufficient rainfall to produce a good crop anywhere in the valley, but from 1888 to 1890 the precipitation has either been too small, or has come at times when it was of little benefit to agriculture, and it is evident that no dependence can be placed upon the success of farming without irrigation.

The facilities for storing water are reported to be excellent, as there are many localities where water, in small quantities at least, could be held for use during the dry season. The matter has been frequently discussed by the irrigators, but comparatively little work has been done toward making these resources available. Attempts have been made to obtain water by deep wells, one being drilled at Helena to a depth of 1,000 feet. Water was found at 160 feet, but it did not rise to the surface. Another well has been drilled to a depth of 521 feet, and this and other shallower wells are pumped by windmills, each furnishing water for about an acre of ground.

In some portions of the valley are a few swamps and hay lands kept moist by springs or seepage, but in other parts there has been a succession of losses of crops owing to deficiency of water. In the southern part of the valley the irrigators depend upon water from Prickley Pear creek, which flows north from the Jefferson range. A few own private ditches, while others have joined in forming companies in order to build canals and ditches. There has been more or less contention over the division of water. In a few instances it is stated that prior locators whose rights have been confirmed by decisions of court find it more profitable to sell the water to more unfortunate irrigators than to attempt to use it themselves.

DEARBORN AND SUN RIVERS.

The Dearborn and Sun rivers rise in the main range of the Rocky mountains and flow easterly to the Missouri, the Dearborn entering at a point about 50 miles north of Helena and the Sun river at an equal distance further down the river. A large number of creeks flow into the stream between these points, but they are of comparatively little importance in irrigation. On the Dearborn river are several large irrigating canals, the one on the north fork being perhaps the most extensive in the state. There is no continuous record of the amount of water in this stream, the only measurements known being those made at Dearborn on August 9, 1889, the discharge being 47 second-feet, and on April 15, 1890, 37 second-feet. The drainage area at this point is about 350 square miles.

In this vicinity are large areas of table or bench land along the Missouri river and extending back to the mountains. The soil on these lands would be very productive if an ample supply of water could be secured. The Missouri river, however, is, as in the case of Prickly Pear valley, at too low an elevation to furnish the needed supply. In times of drought the small streams become dry often at points above the heads of the farmers' ditches. Even the comparatively large streams, as the Dearborn and Sun, contract to such an extent that it becomes a matter of conjecture as to where the water for the large canals is to come from.

Along the beds of the small dry creeks a number of storage reservoirs have been built by ranchmen, who find that in this way they can save enough water to bring under irrigation patches of forage crop of considerable size. This method of saving water is being gradually extended, although the capital invested in such works is small on account of the limited means of the owners. Water is always plentiful in the spring, and if advantage is taken of this fact at the proper time these small ponds can be filled.

The Sun river has been described with considerable detail in the second annual report,[1] where is given a map of the basin, showing the reservoirs and canal lines surveyed by H. M. Wilson. The details of the work are given on page 121 of this volume. The discharge of the Sun river is shown graphically on Plate LXIII of the third annual report,[2] and the maximum, minimum, and mean discharges by months are given in the table on page 347 of the same volume. By reference to this table it will be seen that the discharge for 1890 ranged from 160 second-feet up to 4,085 second-feet. The average for the year was 715 second-feet, this amount of water coming from a drainage area of about 1,175 square miles. The possible utilization of this water out upon the great plains on both sides of the Sun river, both in Lewis and Clarke and Choteau counties, and in Cascade county, above Great Falls, has been discussed by Mr. Wilson in other reports.

The irrigators depending for water upon the smaller streams in this part of the country state that the water supply is barely sufficient for present demands, and that there are large tracts of land on every side now valueless for lack of water. Much of this can be irrigated only by storing the spring floods, but, unfortunately, the farmers do not have sufficient capital to build the small reservoirs. The demand for water is increasing with great rapidity since the ranges upon which the cattle have been accustomed to feed are being fenced and the stockmen are compelled to raise more and more feed for their cattle.

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation, pages 120 to 133.

[2] Twelfth Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation, p. 234.

The drainage basin of the Dearborn river, the south part of that of the Sun river, and the Prickly Pear valley are principally in Lewis and Clarke county, in which area, according to the last census, there were 231 irrigators, and a total of 15,441 acres irrigated from which crops were obtained. The average size of the area irrigated by each person was thus 67 acres, an amount considerably less than the average for the state, but still large when compared with the carefully cultivated areas of Utah and of adjoining states.

CHESTNUT VALLEY AND SMITH RIVER.

Chestnut valley is the term applied to the open land along the Missouri river above Great Falls and north of the Big Belt mountains. Smith river, which drains the country between the Big and Little Belt mountains, enters the Missouri river near the lower end of this valley. A large proportion of the lower land of this area can be irrigated by means of a canal from the Missouri. One canal has already been built, but owing to improper plan or construction a sufficient supply of water could not be turned into it during the drought of 1889 and succeeding years.

The quantity of water in the river available for irrigation is very large, as shown by measurements made at various points referred to on the preceding pages. The daily discharge at Craig, a point north of Helena and above the mouth of the Dearborn river, is shown in Fig. 55. The discharge in 1891, as indicated by the light line, was considerably less than in 1892. This figure should be compared with Pl. LXII of the Twelfth Annual Report,[1] which also gives diagrammatically the discharge during the early part of 1891, together with the quantities for 1890 and for the latter part of 1889. The increased discharge of 1892 over that for 1890 and 1891 is especially noticeable.

There is a large amount of bottom land along the Missouri river usually overflowed each year in the month of June and producing heavy crops of wild hay. Occasionally, however, in years of drought there is no overflow and little hay can be cut. The construction of canals built in such manner as to insure a permanent supply of water for the valley must necessarily involve large expenditures, but the certainty of securing water offers inducements toward investment of this character. In this part of the state there have been a number of large canals built at heavy expense, but which have been to a greater or less degree failures on account of errors of judgment as to the quantity of water available or through poor engineering in locating the line of canal.

---

[1] U. S. Geol. Survey, Twelfth Ann. Rept., pt. II, Irrigation, p. 232.

It is stated that the charge for water from the large canal in Chestnut valley is $2 per miner's inch a season, and that one-half an inch to the acre is sufficient, but in dry seasons the farmers claim that they can not succeed in raising good crops with this amount of water. Occasionally fair crops can be raised without irrigation, but with a thorough system every acre of this beautiful valley could be made to produce large crops every year.

The headwaters of Smith river are in Meagher county, while the lower part, near Chestnut valley, is in Cascade county. As in the case of nearly all streams which flow from one county to another, there is more or less friction among the irrigators of each locality regarding the distribution of the water during the summer. In the upper valleys, where the agricultural areas are small, the water supply is comparatively abundant and is used freely and even wastefully on hay lands. Further down the amount of water available steadily diminishes until the point is finally reached where there is not sufficient for the land usually cultivated.

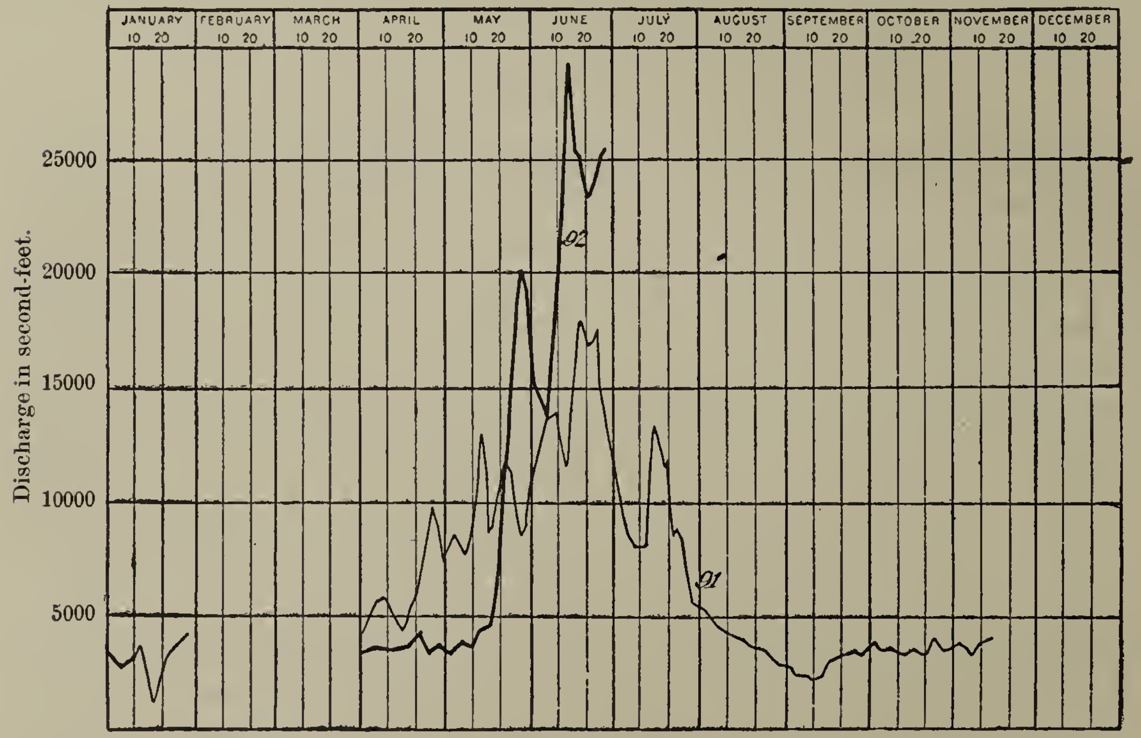


FIG. 55.—Diagram of daily discharge of Missouri river at Craig, Montana, for 1891 and 1892.

On the headwaters of the south fork of Smith river from 15 to 20 miles southerly from White Sulphur springs a number of reservoirs have been examined by the Geological Survey and reported for segregation as described on pages 137 et seq., of the third annual report. At White Sulphur springs the valley has an elevation of about 5,000 feet, and the Smith river is usually considered as a small sized creek. All of the ditches in this vicinity are owned by individuals who take as much water from the streams as they need. Occasionally, however, when there is an unusual drought there is even at this point considerable litigation concerning the distribution of this water. Probably more land could be brought under cultivation if storage reservoirs were constructed in the localities favorable for such work.

In the eastern end of Cascade county near the lower part of Smith river valley the country is in general broken, and the only part suitable for cultivation is that along small, narrow bottoms in the coulees which lead down from the mountains to some water course. In some of these coulees, or draws as they are locally called, there are small streams of water from springs which flow even during the dry season. This water is used by each settler in irrigating a few acres of grain or a garden, but there are few ditches of notable size. There has been little, if any, effort made to provide water storage.

East of Smith river are a number of streams deriving their water from the northern end of the Little Belt mountains or from the Highwood mountains which occupy an almost isolated position to the north of these. A few ditches have been taken out of Little Belt creek, Otter creek and Big Belt creek, but these were of comparatively little use during times of severe drought. In fact, as stated by one of the irrigators, when there is sufficient water to fill the ditches no irrigation is needed and they are practically useless. On the other hand, when the drought is unusually severe the only possible means of irrigation would be by water held in reservoirs near the Highwood mountains.

TETON AND MARIAS RIVERS.

The Teton and Marias rivers rise in the Rocky mountains in the northwestern corner of the Missouri basin and flow in an easterly direction through a region of elevated plains and prairies, finally joining the Missouri river. The general altitude of this country is from 3,000 to 4,000 feet, towards the mountains the plains rising by gentle terraces to elevations of about 5,000 feet. This, as shown on Pl. CVIII, is a broad grazing country, cattle finding an ample supply of grass, especially during years of ordinary rainfall. There are very few cultivated farms, and these are found along the streams where water can be obtained.

On these plains crops can occasionally be raised without irrigation, but there is by no means certainty of success in any year. There are few settlements in this part of Montana, the towns being mainly along the Missouri river. Irrigation is practiced principally near the headwaters of the Teton river, and also on the Marias to a small extent. At various times large irrigating systems have been proposed to take water from these streams out upon the almost limitless plains lying in all directions. On the Blackfeet agency a small ditch has been built and the ground under it cultivated. The Indians attempted to raise crops without irrigation, but during 1889 and 1890 these were a failure.

Along Dupuyer creek, the most southerly of the upper tributaries of the Marias, ditches have been taken out by ranchmen either for the purpose of making hay from the wild prairie grass or for the cultivation of crops. The fall of the land affords means for the easy and rapid construction of ditches and the water of the creek is all taken or claimed, except the flood waters of spring. The surroundings are reported to be very favorable for the construction of reservoirs, but the cost is beyond the means of individuals. The losses for want of water in 1889 in the valley of the Dupuyer alone are stated to have been nearly $40,000. The land is very fertile and produces remarkable quantities of wheat, oats, barley and potatoes.

All along the foot of the Rocky mountains in this part of the basin of the Missouri river are small streams which can be utilized for irrigation, covering the level land in their immediate vicinity. Further out on the plains, however, where the soil is of great fertility, the water supply is very scanty and can only be increased by the most careful system of storage. It is not probable that more than a small percentage of this vast area can ever be cultivated by means of irrigation, and it must remain useful only as pasturage. There are many natural basins into which water from melting snow could be conducted and held for use upon lower grounds in July and August. At present most of this land belongs to the government and affords free pasturage, so that there is little necessity of raising forage plants.

The valley of the Teton is in places 3 miles wide and is at least 70 miles long. Stock-raising is the principal industry, for, since the only railroad is along the Missouri river, there are no facilities for transporting products. It has not been found profitable to raise grain, but the land is rich and with irrigation will produce large crops. On August 7, 1889, the Teton at Choteau was discharging 26 second-feet.

JUDITH AND MUSSELSHELL RIVERS.

The Judith and Musselshell rivers receive the greater part of the drainage of the Missouri basin east of the Little Belt mountains and south of the main river. The headwaters of the Musselshell are south of those of the Judith, this stream flowing in an easterly direction for over 100 miles out upon the Great Plain region before turning north to join the Missouri. Both of these streams receive water from broad basins partially encircled by mountains rising to heights of from 6,000 to 9,000 feet. The general elevation of these upper valleys is a little over 4,000 feet. They are comparatively well watered, many streams issuing from the mountains at short intervals. As a consequence there are a great many small ditches owned by individuals and few, if any, systems of irrigation owned by corporations.

In the Judith basin there is occasionally a year during which a paying crop can be raised without irrigation by the careful cultivation of certain lands, but there is seldom a time in which the crops would not be better by the employment of water. It is stated that 1887 was the wettest year known, and that in 1888 there was ample rain until the 1st of July. In both of these years, good crops were raised in the valley without the use of water, but in 1889 and 1890, the snows in the mountains were very light and the rainfall so deficient that as a consequence most of the crops failed even where settlers were prepared to irrigate, the streams not furnishing sufficient water. A number of storage sites have beeen selected by this survey, and by the construction of reservoirs in these or other favorable localities the cultivated area could be greatly extended.

Judith valley was settled within a comparatively few years, the first ditch being taken out of the Judith river in 1880. As is usually the case, the majority of farmers were poor and made their ditches at as little expense as possible. As a consequence many of these are inefficient and there is considerable waste of water. The claim is made by the farmers that better ditches are needed, as well as laws to regulate the use of water, especially during the time of drought, which begins in the latter part of July. The greater part of the drainage basin of the Judith and Musselshell rivers is included within Fergus county, where, according to the last census, there were 251 irrigators, having a total of 30,401 acres of crops under irrigation. The average size of crop area per individual, viz, 121 acres, shows that most of this must have been devoted to raising hay.

The headwaters of Musselshell river are on the south side of the Little Belt mountains, many streams coming from the Elk mountains on the west and the Crazy mountains on the south. The principal areas irrigated are in the vicinity of Martindale. In this vicinity each farm or ranch as a rule has a ditch of its own, and the bottom lands along the streams are alone watered, these being but a small fraction of the arable land which could be brought under irrigation if reservoirs were constructed on the small tributaries. On each of the small streams there are usually several persons claiming the water which is sufficient to supply only one farm. The bench land, which now furnishes scanty feed to cattle, would with irrigation produce good grain or pasturage for large herds. At the head of many of these creeks or along their course reservoir sites have been segregated.

A few measurements of streams have been made in this vicinity, and it was found that on August 17, 1889, North Musselshell at Martindale was flowing at the rate of 15 second-feet and South Musselshell 10 second-feet. On the same day Lebo creek was discharging 8 second-feet, American fork 3 second-feet, and Elk creek 10 second-feet. This portion of the drainage basin is in Meagher county. Farther down the stream, in Fergus county, the demand for water is even greater than at points higher on the stream, as the valley is broader, and there are thousands of acres of arable land which could be covered by canals. The tributaries which enter the Musselshell in the lower portion of its course all come from the Big Snowy mountains and contribute water only in times of flood. During the summer all of the amount available is used for irrigation on the ranches near the foothills of these mountains.

The country on both sides of the Missouri river, from above the mouth of the Judith river down to the Musselshell and even to the junction of the Yellowstone, consists largely of bad lands, in which there is no water, except in a few streams, which are from 50 to 200 feet lower than the land. There is some level land on the divide, but it is useless on account of the absence of water.

MILK RIVER.

Milk river rises in the Rocky mountains near the northern border of Montana, the greater part of the headwaters being within the Dominion of Canada, in the territory of Alberta. It flows in a general easterly direction, being in the middle third of its course nearly parallel to the Missouri, and finally turning toward the south enters the latter stream about 120 miles above the junction with the Yellowstone. For nearly its whole length it flows through prairies or high plains, from which it receives little water. The greater part of the drainage area in Montana has been until within a few years included in a vast Indian reservation, and therefore agriculture has not had an opportunity to develop. By the throwing open of the Milk River valley to settlement, however, rapid progress has been made and the possibilities of the region have begun to attract attention.

Previous to the throwing open of the Indian reservation in Milk River valley there had been experiments in farming made by white men living in the reservation, and also by the Indians, dependence for water supply being placed upon melting snow and rainfall. A crop raised in 1888 demonstrated that all kinds of grain and vegetables, flax, hemp, and to a limited extent fruit, can be produced. Water can be taken from Milk river in many places by ditches, but the stream becomes very low after the spring freshets.

The whole of the eastern end of the Missouri basin is a vast prairie country with scanty vegetation, and is in general suitable only for pasturage. There are a few localities where water can be diverted from the main stream or held in reservoirs and small patches of low land brought under irrigation. While these areas are of themselves important in this vast extent of pasture land, yet in size they are almost insignificant. There is occasionally a year during which crops can be raised without the application of water, but the uncertainty is so great that it would be ruinous for a farmer to attempt to make a living in this way. The small creeks shown on the map as draining the eastern part of the basin are usually dry for a great part of the year, although at certain times they carry a large amount of water. No measurements have been made of the amount of water available in the Milk river or in any of these streams. The Missouri river itself has been gauged at various points along this part of its course by officers of the Missouri River Commission in the course of their surveys for the purpose of improving navigation. The results of these measurements are noted on page 237 of the third annual report.[1] As there stated, the estimated mean daily discharge in 1879 was 13,530 second-feet, and in 1880 was 18,151 second-feet. As is obvious, this amount of water is far in excess of any demands which could ever be made for the purposes of irrigation.

YELLOWSTONE RIVER BASIN.

LOCATION.

The drainage basin of the Yellowstone river, as shown by the small index map, Fig. 51, lies south and partly east of the Missouri basin, above described. Continuing in order around the basin, on the east are the head waters or streams flowing into the Missouri in the Dakotas and Nebraska; on the south is the basin of the Platte and that of the Colorado, and on the southwest the tributaries of Snake river, one of the branches of the Columbia. The Yellowstone basin is separated from the head waters of the Colorado and Columbia by the continental divide, which in this portion of its course is made up in places of a high, undulating country, in which the line of water parting is not sharply defined.

The Yellowstone river rises in the national park to which the stream has given its name, flows north through deep canyons into the state of Montana, and then pursues a general northeasterly course to the junction with the Missouri river near Fort Buford, a few miles east of the state line between North Dakota and Montana. The principal tributary of the Yellowstone, the Bighorn, rises in the Wind River mountains, near the center of Wyoming, and, flowing northerly, unites with the Yellowstone about halfway from its source to mouth. Other streams, as, for example, the Tongue and Powder rivers, flow from Wyoming in a northerly course, parallel to that of the Bighorn, entering at points below the mouth of the latter stream.

As will be seen by inspection of the map, Pl. CIX, the Yellowstone river flows along the northern side of its drainage basin, its water being received almost entirely from rivers coming in from the south and heading in the Absaroka and Bighorn ranges. The east and west line forming the boundary between the states of Wyoming and Montana cuts across the headwaters of all these streams, so that as a broad statement it may be said that three-fourths of the water in the Yellowstone comes from the state of Wyoming, while the largest extent of irrigable land is probably in Montana.

---

[1] Twelfth Ann. Rept. U. S. Geol. Survey, 1890-91, pt. II, Irrigation.

AREA AND TOPOGRAPHY.

The total area of this basin is approximately 69,683 square miles, of which 36,312 square miles, or a little over one-half, are in the state of Montana. Measuring the elevation of the basin as shown by the contour lines on the map, it has been found that the areas at various altitudes are as follows:

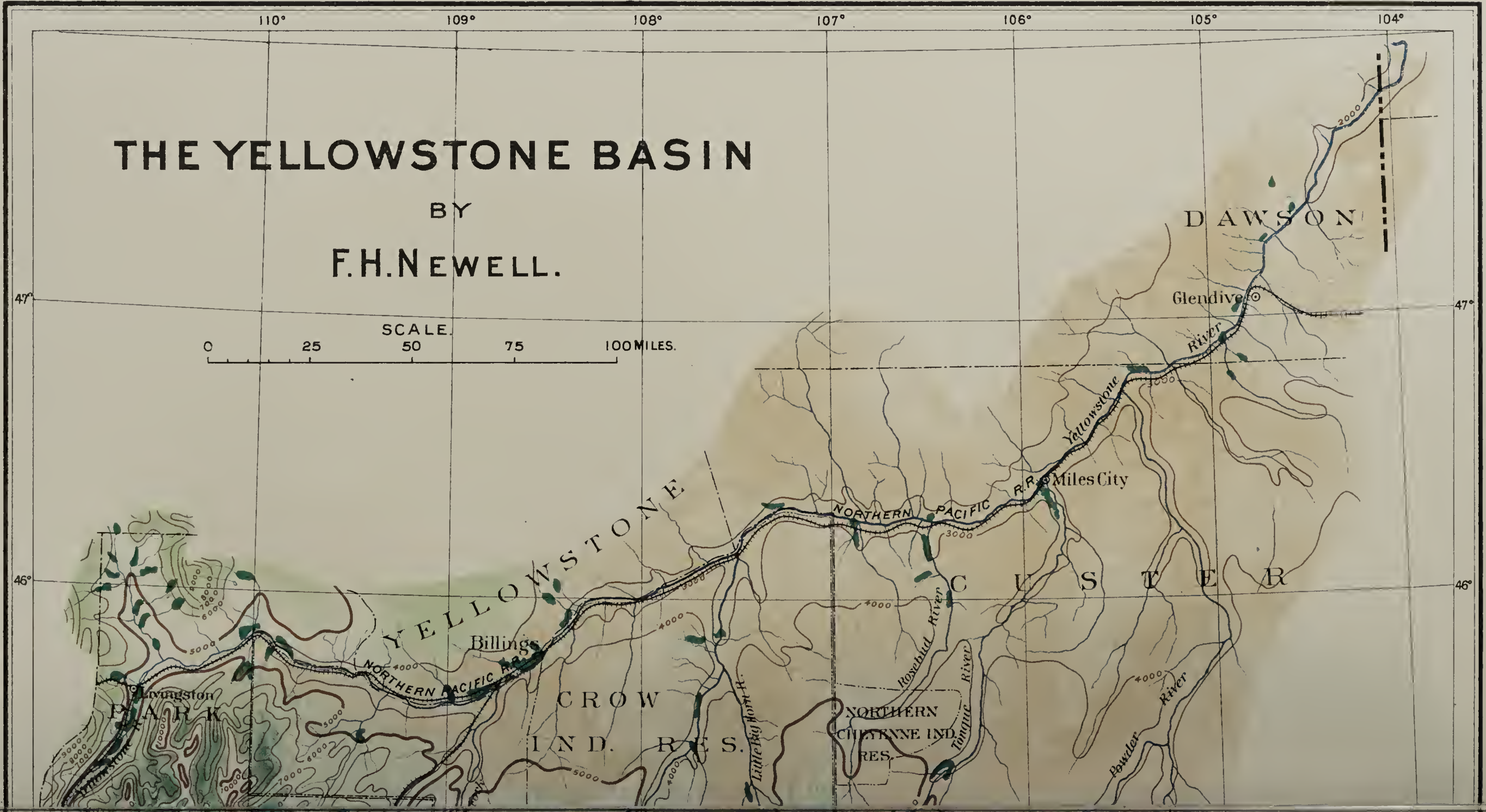
	Square miles.
Area under 2,000 feet	200
Area from 2,000 to 3,000 feet	6, 340
Area from 3,000 to 4,000 feet	12, 288
Area from 4,000 to 5,000 feet	12, 265
Area from 5,000 to 7,000 feet	23, 605
Area over 7,000 feet	14, 985

In general outline the basin, as shown by the map, is rudely triangular, a long point extending toward the northeast. All of the high ground is in the opposite direction, namely, near the southwestern side, the basin as a whole falling off rapidly toward the region of the great plains of the Dakotas and eastern Montana. The high mountains in the elevated portions of the basin, rising to altitudes of 10,000 feet and over, furnish a large and perennial supply to the streams, so that, although the drainage area is less, the amount discharged by the Yellowstone at the junction of the two streams is probably nearly equal to that flowing in the Missouri.

One of the chief characteristics of this basin is the great extent and elevation of these mountain masses occupying the southwestern part of the area. These fall into two groups, separated by the Bighorn river, the first of these being the Absaroka range, together with the Snowy mountains on the north and the Wind river range on the south, and second, the Bighorn range, lying far to the east. These great mountain masses receive an amount of precipitation unusually large for the arid region. The greater part of this comes in the form of snow, which, melting during the summer, furnishes a large amount of water to the widely distributed streams flowing out in all directions. Thus owing to the excellent water supply there are unusual opportunities for the development of irrigation wherever arable land is to be found.

In the northeastern part of the basin are plains deeply cut by the larger rivers issuing from the mountains and also by the streams which at certain times of the year carry away the storm water of the comparatively level country. On the eastern edge of the basin the plains have been deeply eroded and begin to pass into the condition of "bad lands," a type of country which prevails in the vicinity of the Black Hills.

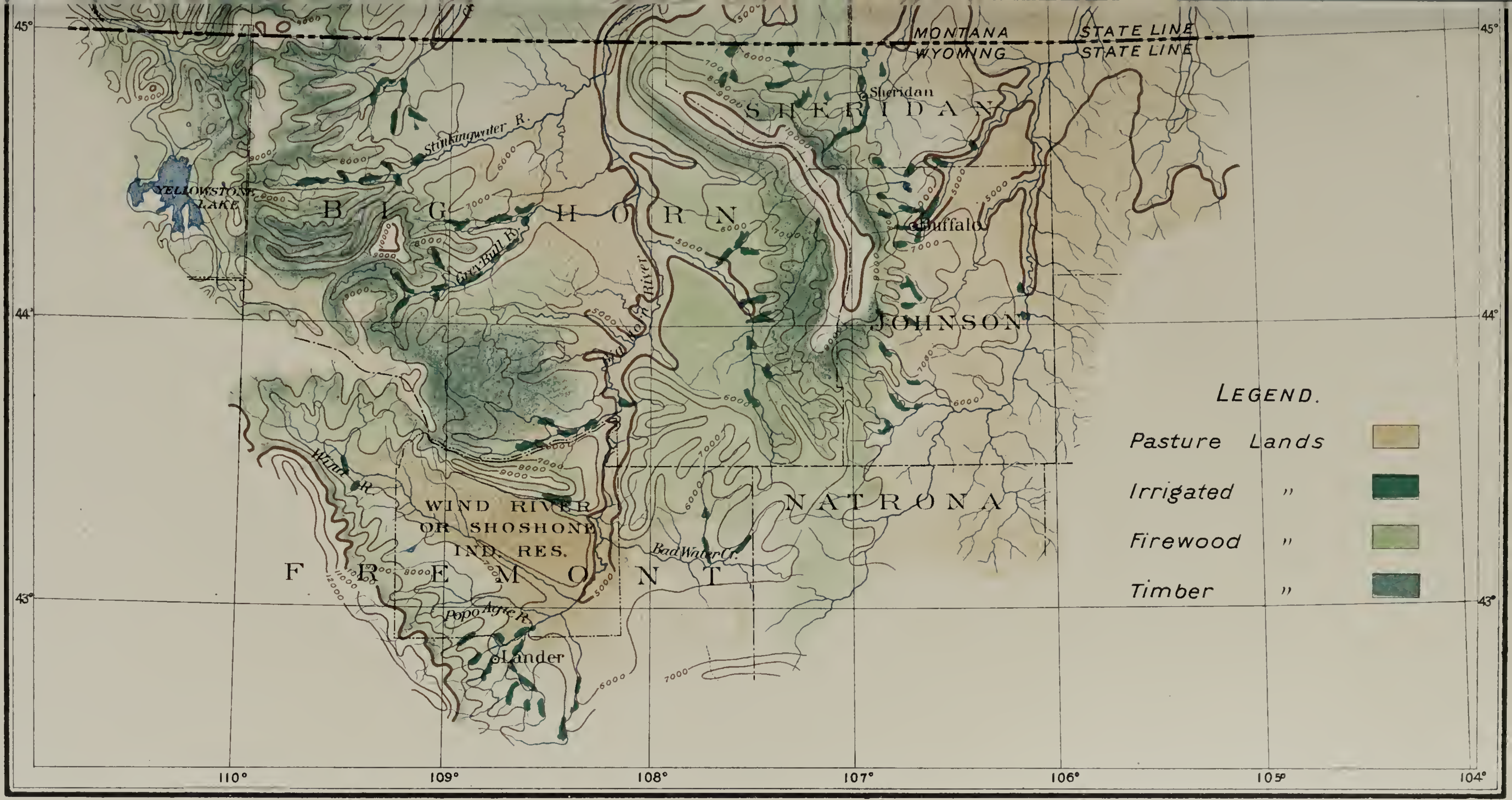
The lofty slopes of the mountain ranges are thickly clothed with timber, some of it of great value, becoming more so as settlement advances. The map, Pl. CIX, has been colored to show the general distribution of this timber and also of the areas containing a notable amount of wood suitable for fuel. The remainder of the drainage basin consists for the



THE YELLOWSTONE BASIN

BY

F. H. NEWELL.



Geo. S. Harris & Sons Lith. Phila

most part of grazing or hay lands, there being few localities in which food for cattle can not be found during a part of the year at least. The area covered in whole or in part by timber has been estimated to be 11,320 square miles, and by scattering firewood 13,580 square miles, leaving 44,783 square miles suitable for grazing, a small part of this being so situated that it can be brought under cultivation by irrigation.

AREA IRRIGATED.

In this basin the total area irrigated and from which crops were obtained in 1889, as shown by the Eleventh census, was 108,934 acres, or 170·21 square miles. This is only 0·38 per cent of the total area considered as pasture land, the soil of most of which is fertile and only needs the application of water to produce good crops. There are within the basin a few localities where farmers are moderately successful without irrigation, but these cases are considered as exceptional, for, as a rule, the rainfall, although heaviest in the summer season, is insufficient for the needs of most crops.

The places at which irrigation has been carried on are shown on the map by the dark spots, the area of these, however, not being in true proportion, but are somewhat exaggerated in order to make them apparent. Along the rivers a portion of the lower land has been distinguished by a different tint to indicate the irrigable areas or lands to which water may be brought in the future, the area and location of these depending of course upon the manner in which the water supply is utilized.

WATER MEASUREMENTS.

The measurements of the amount of water flowing in the Yellowstone made by the Geological Survey have been described in the previous report[1] where are also given the results of four gaugings made below Yellowstone lake. In addition measurements have been made by officers of the Engineer Corps, U. S. Army, giving the total amount of water carried at various points on the main stream.[2] One of these, made at the junction of the Bighorn and Yellowstone in August, 1879, showed that the Yellowstone above the Bighorn was discharging at the rate of 7,471 second-feet and the Bighorn 5,865 second-feet, making the total discharge below this point 13,336 second-feet. Further down stream, at Fort Keogh, above Miles City, in September, 1878, the discharge was 14,462 second-feet, and in October, 1879, 6,505 second-feet, showing a comparatively wide range for the late summer season. At Wolf rapids, about a mile below the mouth of Powder river, the discharge in September, 1878, was 11,235 second-feet, and at Diamond island, about 30 miles above the junction of the Missouri, the discharge in October, 1878, was 8,155 second-feet. The above, with one gauging of the Bighorn made by W. H. Graves, engineer of the Indian bureau, comprise nearly all the data available. This latter measurement of the Bighorn was made near the mouth of the canyon on September 4, 1891. The width of the river was 257 feet, the average depth 2·91 feet, the rate of flow 4·28 feet per second, and the computed discharge 3,200 second-feet. The drainage basin at this locality is about 18,000 square miles, and the average fall from the canyon down to Fort Custer 7 feet per mile.

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation, pp. 36–38; see also tables in Appendix of this report, p. 93.

[2] Ann. Rept. Chief of Eng., U. S. Army, 1880, p. 1476. See also report for 1879, p. 1101, and for 1883, p. 1351. For distances, fall, and rate of fall per mile see report for 1880, p. 1477.

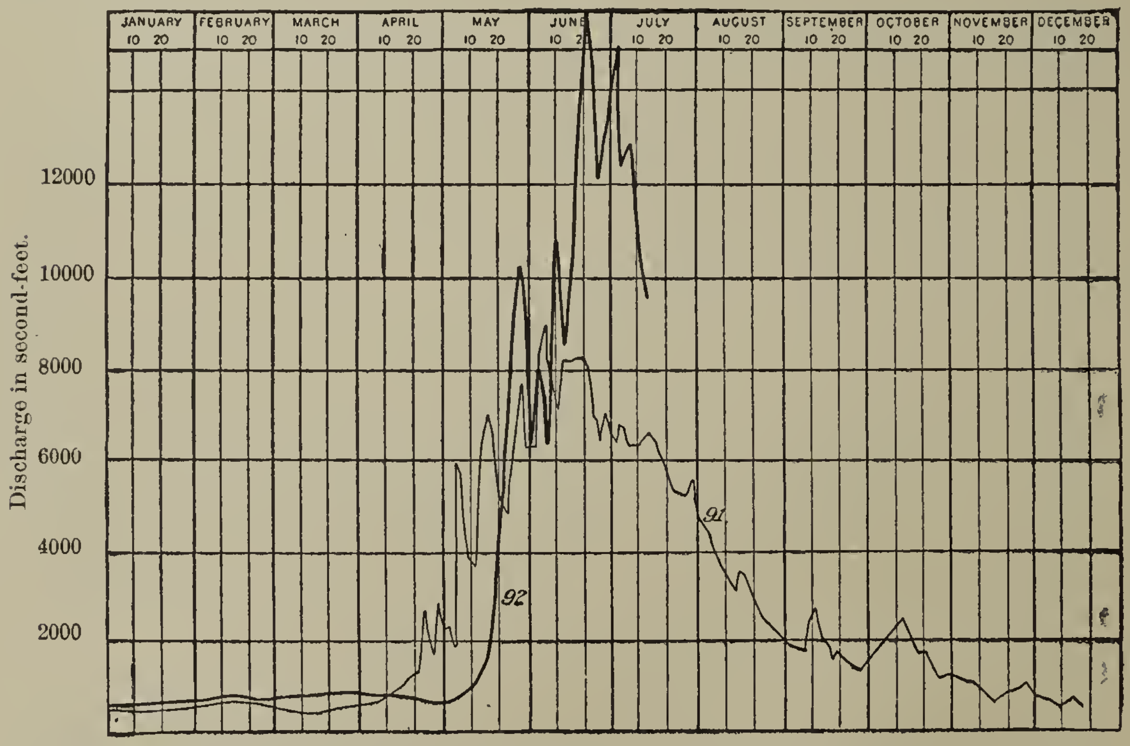


FIG. 56.—Diagram of daily discharge of Yellowstone river near Horr, Montana, for 1891 and 1892.

Observations of the height of the river at Horr, about 4 miles below Cinnabar, have been made by the Geological Survey since August, 1889, giving data from which to compute the daily discharge as shown on Fig. 56.[1] Above this point the water has not been diverted, a great part of the area drained being within the Yellowstone National park. The features of this wonderful country have been described in many publications, notably in the volumes of the U. S. Geological and Geographical Survey of the Territories, commonly known as the "Hayden Survey," from its chief, Dr. F. V. Hayden. In this connection it is sufficient to state that the catchment basin of the river above Horr consists of a high volcanic plateau, situated at a mean elevation of about 8,000 feet, surrounded by rugged mountain ranges whose summits rise to altitudes of from 10,000 to 11,000 feet and over above sea level. Yellowstone lake is a natural reservoir tending to equalize the flow of the river and in which if necessary an enormous amount of water could be held at relatively small expense. It is doubtful, however, whether this will ever be desirable, since the Yellowstone River carries an amount of water far in excess of the needs of the lands which can be brought under ditch by ordinary means.

---

[1] See also Twelfth Ann. Rept. U. S. Geol. Survey, Pl. LXIV, p. 236.

A few measurements were made at Springdale, east of Livingston, and about 70 miles below Horr, but the results at this place did not materially differ from those at Horr, and therefore work at that point was abandoned. Near the headwaters of the Tongue and Powder rivers the state engineer of Wyoming has made a number of gaugings of streams of importance in irrigation. A brief statement of the results of these measurements is given further on in the description of the basins of the rivers mentioned.

As a general statement it may be said that the amount of water in the Yellowstone and its principal tributary, the Bighorn, is far in excess of any demand to be made upon it. It does not seem credible that irrigation works will ever be constructed of a magnitude such that a serious diminution of the annual discharge will take place. In the case of the small tributaries, however, issuing from the eastern side of the Absaroka and other ranges of this group and from the Bighorn mountains, where the supply, though in the aggregate large, is well distributed, the amount ordinarily available is not sufficient for all demands. In these localities are many valleys where on account of the rapid fall of the streams water can be readily diverted upon arable lands and in the aggregate thousands of acres brought under cultivation. It is in such places that economy in the use of water must be observed and the summer flow increased, if possible, by the construction of storage reservoirs.

PRECIPITATION.

In the Yellowstone basin there are comparatively few localities at which measurements of the amount of rainfall have been made. The longest records are those which have been kept by post surgeons at various camps and forts. From these records, collected and published by the Signal Service of the Army, it is apparent that the annual precipitation ranges from 10 inches on the plains in the northeastern part of the basin up to 30 inches or over in the valleys among the mountains. No observations have been made as to the depth of precipitation on the high summits, but it is probable that it amounts to as much as 40 inches or even more.

In the following list are given the names of the principal stations at which measurements have been made, together with the number of years and the average depth of precipitation:

Locality.	Length of record.	Average depth of rainfall.
	Years.	*Inches.*
Camp Sheridan, near Mammoth Hot springs, Yellowstone National park	2	25·46
Fort Washakie, 15 miles northwest of Lander, Wyoming	9	10·14
Fort McKinney, at Buffalo, Wyoming	4	10·53
Fort Custer, Montana, at mouth of Little Bighorn	10	13·16
Fort Keogh, near Miles, Montana	12	12·90
Glendive, Montana	2	10·15

The first of these stations, that in the Yellowstone National park, is at an altitude of over 6,300 feet, and is surrounded by high peaks, and thus, as might be expected, the amount of precipitation is relatively great. Most of this comes in the winter months, and in this respect differs from records at other localities in the basin. The distribution of rainfall during the year at these places is similar in most respects to that in the Missouri basin, the greater part of the rainfall occurring in May and June, as shown graphically on Fig. 52.

Taking the mean monthly rainfall at the stations named above, excepting Camp Sheridan, the precipitation per month obtained by averaging these is as follows:

	Inches.	Per cent.
January	0·64	5·7
February	0·50	4·5
March	0·56	5·0
April	1·05	9.4
May	2·13	19·1
June	1·88	16·9
July	1·25	11·2
August	0·92	8·3
September	0·86	7·7
October	0·67	6·0
November	0·36	3·2
December	0·34	3·0
Total	11·16	100·0

YELLOWSTONE RIVER ABOVE BIGHORN.

In a detailed description of the water supply of the Yellowstone basin it becomes convenient to divide the whole area into a number of sub-basins, each embracing the catchment of a large tributary or a portion of the main stream. The first of these sub-basins may be taken as that portion of the Yellowstone basin which includes the headwaters down to the mouth of the Bighorn river. Next in geographic order on the east is the basin of the Bighorn, succeeded by those of the Tongue and of the Powder river, and finally the remaining area tributary to the lower part of the main stream.

The general character of the catchment basin of the Upper Yellowstone has been briefly described above. After leaving the great canyons below the National park the river flows through a narrow valley, in which a small amount of irrigation is practiced, mainly by means of water from mountain streams. At the northern end of this valley the river passes through the lower canyon and shortly beyond this locality takes a general course toward the east, the lowlands becoming wider and better adapted for agricultural purposes. As shown by the map, the river partially encircles the northern end of the Absaroka or Snowy range, receiving from these lofty mountains a great number of streams which flow out toward almost every point of the compass, emptying directly into the Yellowstone, or, uniting, form large tributaries, such, for example, as Clarke Fork. These streams carry a perennial supply of water, which is utilized wherever possible upon the lowlands in the narrow valleys. The streams coming into the river from the lower mountain ranges on the left hand, viz, the western or northern side, discharge a relatively small amount of water, the quantity being far less than that needed to supply the agricultural land, and as a consequence there have been quarrels and expensive litigation concerning the division of water. In a number of instances attempts have been made to increase the summer discharge of small streams by the construction of storage reservoirs by farmers, working singly or in partnership.

Little if any water is taken from the main river until a point about 30 miles above Billings is reached. At and below this point are a number of canals and ditches on the north side covering land in the vicinity of Park city, and from thence down to Billings. The principal of these in order are the canal of the Minnesota and Montana Land and Improvement Company, the Italian Company's ditch, Mill ditch, Clarkes Fork ditch, and the Yellowstone and Canyon creek ditch.

Clarkes fork enters the Yellowstone from the south side about 10 miles east of Park city. It discharges a large quantity of water, the amount of which has not been ascertained. Irrigation is carried on at various places along the head waters in Bighorn county, Wyoming, but owing to the fact that the stream throughout its course in Montana is within the area lately a part of the Crow Indian reservation the waters in that State have not been utilized.

BIGHORN RIVER.

The Bighorn river rises on the northeasterly side of the Wind river mountains and flows northerly between the Bighorn and Absaroka ranges, receiving many large tributaries from both of these great mountain masses. The water supply is in excess of any demands likely to be made upon it for many years, owing to the fact that the larger bodies of agricultural land along its course can only be reached by long and expensive canals. The greater part of this basin is comparatively inaccessible, owing to the distance from lines of transportation. The principal industries are mining and stock raising, a small amount of irrigation being practiced on lands mainly near mining camps or on the low grounds of cattle ranches. The White river or Shoshone Indian reservation in Wyoming and the Crow Indian reservation in Montana cover some of the best land in this basin, but outside of these are many localities to which water can profitably be brought.

The greater part of the irrigation is in the vicinity of Lander, south of the Wind river reservation, water for the cultivated lands being taken from the Popo Agie and its tributaries. From this point northerly along the base of the mountains on both sides of the river water has been diverted in a small way from the head waters of the Wind river, Owl creek, Grey Bull, Badwater, and other streams. There are no large canals, but many ditches dug by individuals or by a number of irrigators acting in partnership.

Measurements of the amount of water in many of the small streams in the vicinity of Lander were made by the state engineer during the summer of 1892,[1] the principal results of which are given in round numbers in the following table:

Date.	Stream.	Discharge in second-feet.
June 19, 1892	Beaver creek, at Hailey	70
June 23, 1892	Squaw creek	26
June 27, 1892	Mexican creek	6
July 5, 1892	North Fork Popo Agie river, at Milford bridge	619
July 20, 1892	Middle Fork Popo Agie river, near Lander	343
Aug. 4, 1892	Little Popo Agie river	67
Aug. 8, 1892	Cherry creek	9
Aug. 8, 1892	Red Canyon creek	5

A few measurements were also made about this time giving the discharge of Bighorn river at the ferry at Alamo in Bighorn county. The results showed that on July 10 the mean velocity at this point was 4.72 feet per second, and the total discharge 9,707 second-feet. On July 14 the Stinking Water river at the bride at Corbett had a mean velocity of 6.22 feet per second and was discharging 4,974 second-feet, this water entering the Bighorn about 45 miles below Alamo.

Within the Crow Indian reservation in Montana a small amount of irrigation has been carried on by Indians by use of water from the Little Bighorn. This stream receives water from the northern end of the Bighorn range, and is of sufficient size to irrigate a large acreage. Surveys have been made under the direction of the Indian Bureau, and estimates prepared of the expense of canals in order to determine the feasibility of systems of irrigation supplied with water from the Bighorn and from the Little Bighorn. It has been ascertained that water can be diverted upon the highlands between the two streams or upon those to the west of the main river at a cost per acre sufficiently low to justify construction.

TONGUE RIVER.

The Tongue river heads on the northeasterly slopes of the Bighorn range in Sheridan county, Wyoming. Below the junction of its principal tributaries the river flows in a direction a little east of north through Custer county, Montana, entering the Yellowstone. Irrigation is carried on in Wyoming to a large and constantly increasing extent by means of the many streams draining the high mountains, these being widely distributed and easily diverted upon land among the foothills. On account of this fact Sheridan county is rapidly becoming one of the principal agricultural localities of the state. In the aggregate, however, there is more good farming land than can be irrigated, and along some of the small streams there is occasionally a scanty supply. Gaugings of a few of the more important streams have been made by Prof. Elwood Mead, state engineer of Wyoming. The data[1] furnished by him show that on June 29, 1891, Little Goose creek at Davis ranch discharged 109 second-feet; on July 5, 1889, Big. Goose creek at Beckton bridge discharged 169 second-feet and on July 1, 1893, at Sheridan bridge, 1,009 second-feet; on July 29, 1891, Tongue river at Dayton bridge discharged 192 second-feet, and on July 28 the south fork of Tongue river at Burkitt's flume discharged 18 second-feet.

---

[1] First biennial report of the state engineer to the governor of Wyoming, 1891 and 1892. Cheyenne, Wyoming, 1892. Appendix, p. xxi.

Outside of the foothills it becomes a matter of considerable trouble and expense to divert the water, on account of the banks of the stream in most cases being high and the material of such a nature that it washes away or softens under the action of water. The river is very crooked, crossing the bottom lands from bluff to bluff, rendering it expensive and even impossible to build long ditches. With increase of population, however, it will doubtless be practicable to attempt large schemes to cover the higher lands and utilize most of the water in the main stream.

In its course through Montana there is comparatively little irrigation along the river. A few ditches have been dug, but there are not many localities where water can be diverted at small expense. Attempts have been made to use pumps in order to lift the water up to the top of the steep banks. The bottom lands are usually narrow and so frequently cut by the river in its course from side to side that ditches can not be built. At Miles is the largest ditch along the lower course of the Tongue river. This heads on the east side of the river about 15 miles above the Yellowstone and follows down along the stream to Miles, where it turns off into the valley of the Yellowstone. The water in Tongue river is raised by a dam to a height of about 7 feet above low water, diverting it into the canal.

Between the Bighorn and Powder rivers is the Rosebud, which flows northerly into the Yellowstone. This river does not head in the high mountains, and therefore during a large part of the year is nearly dry. There are probably twenty ditches along the stream, irrigating small areas of hay, grain, and vegetables. In July, August, and September the water often ceases to run, and for sometime during late spring the creek furnishes barely enough for the land under cultivation, so that it will be necessary to store some of the water which flows to waste in the early part of the year in order to utilize a considerable proportion of the agricultural land in this valley.

POWDER RIVER.

The Powder river receives the greater part of its water from the eastern side of the Bighorn range, its upper tributaries being south of those of Tongue river. These are utilized for irrigation at points along the foothills where they can be readily diverted, a comparatively small amount of water escaping to the main river during the irrigating season. The ditches highest up on the stream receive usually an abundant supply, while those lower down are often short of water, causing many controversies which require the intervention of state officers. In 1889 there was an unusual drought, and many of the upper streams, especially those receiving water from the lower foothills, were entirely dry, resulting in large losses of crops. At a distance of from 20 to 50 miles from the mountains the waters of the various streams are fully appropriated, and in many cases the amount called for is far in excess of the ordinary discharge. The measurements made by Prof. Elwood Mead[1] show that on June 3, 1891, Clear creek, at weir in the canyon, discharged 552 second-feet, and on August 3, at the same place, 72 second-feet; also, on August 12, Rock creek below the forks, near Buffalo, Johnson county, discharged 17 second-feet. Many other streams were measured, the result in each case being less than 5 second-feet.

---

[1] First biennial report of the state engineer to the governor of Wyoming, 1891 and 1892. Cheyenne, Wyo., 1892. Appendix, pp. XIX and XXI.

As the Powder river and its tributaries leave the vicinity of the mountains the amount of water available decreases, the expense of taking it out upon the land becomes greater, and long before reaching the Montana line no irrigation is attempted. In its course through Custer county in the latter state the river during a great part of the year ceases to flow, and owing to the character of the country irrigation is practically impossible. This part of the basin of the Yellowstone is within the "bad lands," and has little or no value for agriculture or stock-raising.

LOWER YELLOWSTONE RIVER.

From Billings down to the mouth of the river there are at intervals small areas of irrigated land, these being mainly at places where tributaries enter from the north or south. The amount of water in the river, as shown by the measurements previously mentioned, is very great, but none of this has been diverted by canals on account of the very gentle fall of the stream. In a few localities pumps have been erected and sufficient water raised to cover small gardens or to irrigate trees. The side streams, however, have a greater slope and can be controlled by dams raising the water above the level of the lower land. The largest system of irrigation is that previously mentioned as being in the vicinity of Miles.

On account of the great expense of building canals to cover the low land along the Yellowstone many of the farmers have been compelled to resort to what are known as "high-water" ditches. These are dug at places where during the high water of spring they will receive some of the overflow, carrying it out upon grounds farther down the stream. In this way a large acreage, mainly of hay land, can be given one thorough soaking. Beyond the bottom lands are vast areas of fertile land lying at a height above the river so great that it is improbable that water can ever be brought to them. To irrigate these plains would necessitate the construction of a canal of 100 miles at least in length, and if practicable the expense will doubtless be too great for any ordinary corporation to undertake. To determine the feasibility of such a canal will require careful surveys and a thorough examination of the matter from all standpoints.

---

[1] First biennial report of the state engineer to the governor of Wyoming, 1891 and 1892. Cheyenne, Wyo., 1892. Appendix, p. XIX.

PLATTE RIVER BASIN.

LOCATION AND AREA.

The drainage basin of the Platte above the junction of the north and south branches lies mainly in southeastern Wyoming and northern Colorado, a small portion being within the state of Nebraska. As shown by the index map, Fig. 51, this basin on the northwest adjoins that of the Yellowstone. On the west are the headwaters of the Colorado river, on the south those of the Arkansas, and on the northeast and southeast are the streams which, coming from springs on the Great Plains, flow easterly into the Missouri river. The basin as a whole, as shown by Pl. CX, slopes from the mountains in the southwestern part, both north and easterly, the greatest fall being in the latter direction.

The total area of this basin is 57,320 square miles, of which 24,240 square miles are in Wyoming, 22,230 square miles in Colorado, and 10,850 square miles in Nebraska. Of the area in Colorado 2,025 square miles are included within the drainage basin of the North Platte and 20,205 square miles in that of the South Platte, this latter basin being thus almost entirely within Colorado. The line of watershed of the basins of the North and South Platte is not sharply defined, except among the high mountains. Throughout the Great Plains it is very indefinite, and also in the high almost desert area in Sweetwater county, Wyoming. A somewhat arbitrary line has, therefore, been taken as bounding these sides.

The North Platte rises in the northern part of the main range of the Rocky mountains in Colorado and flows in a general northerly course nearly half across Wyoming. The direction taken by this part of the river shows plainly the general slope of the surface of Wyoming toward the north. A relatively slight depression of the central part of the state would throw the waters of this stream directly into the headwaters of Powder river, which flows northerly on the prolongation of the course taken by the upper part of the North Platte. This latter river, however, shortly after receiving the Sweetwater from the west, begins to swing around toward the east, flowing along the upper edge of the drainage basin, and, having described nearly a half circle around the Laramie hills, takes a southeasterly course and flows for over 150 miles in an almost straight line. The principal tributary, the Laramie river, curves in a manner similar to that of the upper waters of the North Platte. It rises behind the Laramie range, flows northerly, and then gradually turns toward the east, passing through the range to join the main river.

The South Platte rises behind the Front range of the Rocky mountains and, passing out through a canyon, flows along the foothills, collecting in its northerly course the waters of a large number of mountain creeks, each of which issues through a deep canyon. After receiving the Cache la Poudre, the largest stream of this part of the country, the river turns toward the east and flows out through the Great Plains. As the North and the South Platte continue on their way through the comparatively level country they converge at first rapidly and then more and more slowly, flowing within a few miles of each other for a distance of over 50 miles, the bed of the South Platte being probably slightly higher than that of the North Platte.

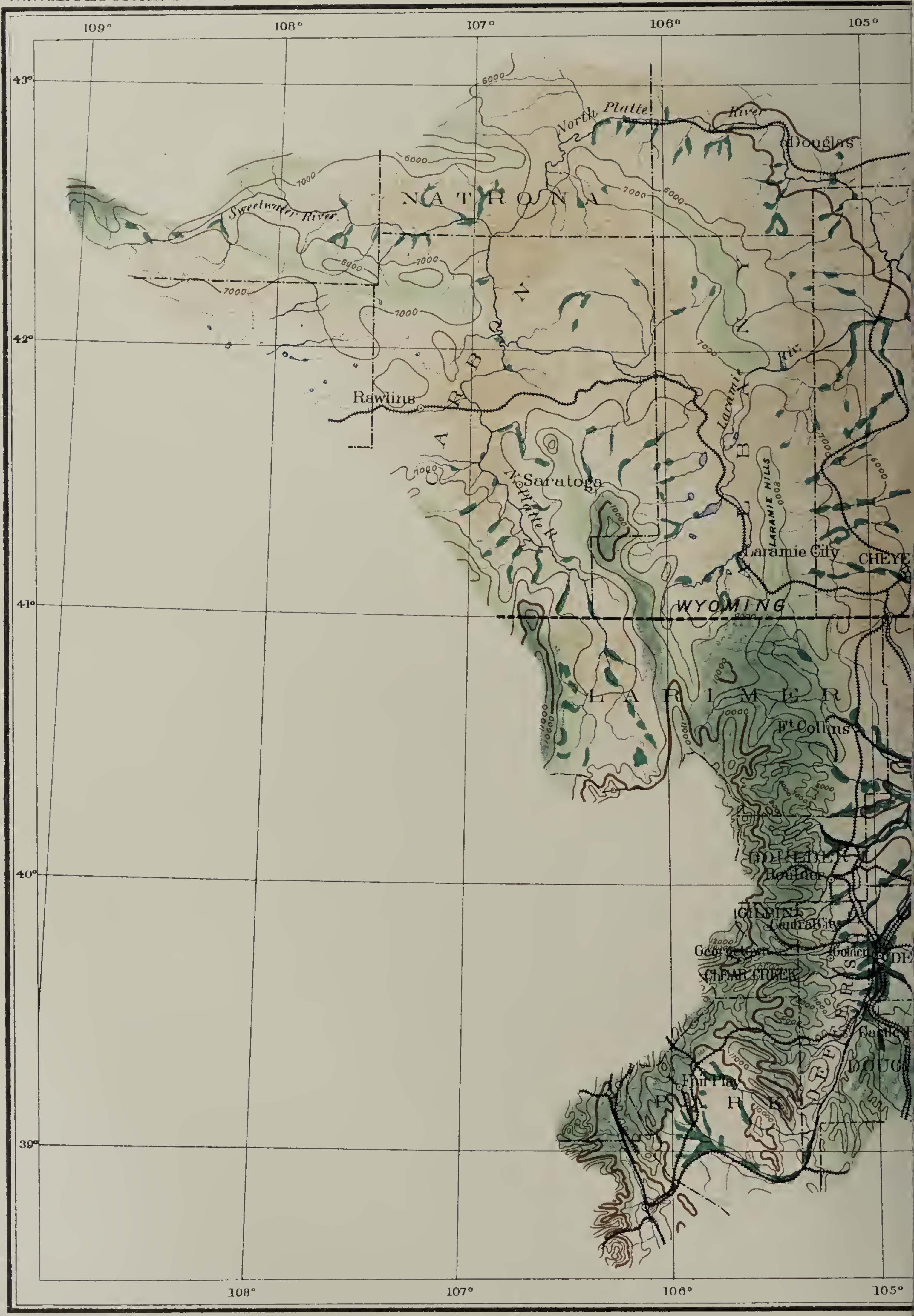
ELEVATION AND TOPOGRAPHY.

The general elevation of the basin is best shown by the following table, prepared by means of measurements of the areas inclosed by contour lines on Pl. CX, this plate being a portion of the large map of the United States compiled by Henry Gannett. The line of the divide, as previously stated, has been arbitrarily assumed in various parts of the more level country.

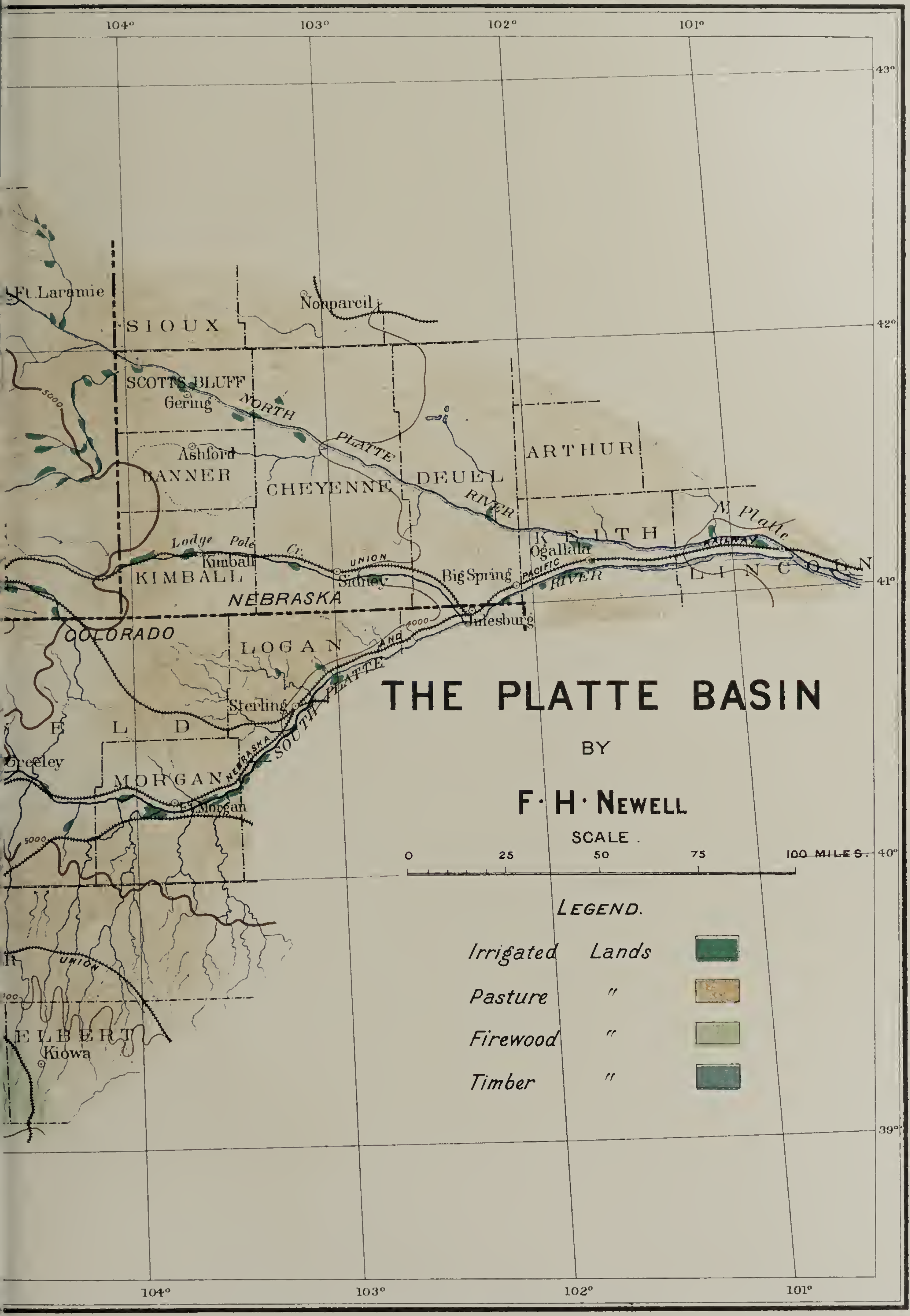
	Square miles.
Total area	57, 320
Area under 3,000 feet	700
Area from 3,000 to 4,000 feet	5, 960
Area from 4,000 to 5,000 feet	14, 660
Area from 5,000 to 7,000 feet	21, 660
Area above 7,000 feet	14, 340

The basin as a whole is among the most elevated in the country, an almost insignificant portion, that near the junction of the two branches, being under 3,000 feet. From this point the country gradually rises, preserving the character of a plain until the altitude of 7,000 feet or over is reached, the base of the mountains being at about this elevation above sea level. On the northern side of the basin the undulating or slightly broken plains, mainly under 7,000 feet in altitude, sweep around through the ranges of the Rocky mountains to the head waters of streams flowing into the Pacific or into the Great Interior basin, and a traveler can pass over the continental divide almost without seeing a mountain peak except in the far distance. In the south half of the basin, however, the Front range of the Rockies presents a bold face to the east and apparently blocks advance toward the west. These

U.S.GEOLOGICAL SURVEY.



GEO.S HARRIS & SONS, LITH PHILA.


104°
103°
102°
101°
43°
42°
41°
40°
39°
Ft. Laramie
Nonpareil
SIOUX
SCOTTS BLUFF
Gering
NORTH PLATTE RIVER
Ashford
BANNER
CHEYENNE
DEUEL
ARTHUR
KEITH
Ogallala
N. Platte
LINCOLN
Lodge Pole Cr.
Kimball
KIMBALL
UNION PACIFIC RAILWAY
Sidney
Big Spring
RIVER
NEBRASKA
COLORADO
Julesburg
LOGAN
SOUTH PLATTE
NEBRASKA AND
Sterling
WELD
Greeley
MORGAN
Ft. Morgan
5000
4000
UNION
ELBERT
Kiowa
THE PLATTE BASIN
BY
F·H·NEWELL
SCALE.
0
25
50
75
100 MILES.
LEGEND.
Irrigated Lands
Pasture "
Firewood "
Timber "

mountains and those to the rear rise to altitudes of from 10,000 to 12,000 feet or more, and their peaks are for a great part of the year covered with snow. Among these are broad parks whose bottom lands are 8,000 feet or more in height. From the North park comes the North Platte, from the Middle park the Grand river, flowing into the Colorado, and from the South park the head waters of the South Platte. These and other smaller valleys are traversed by many streams, and besides furnishing excellent grazing produce large quantities of hay.

LAND CLASSIFICATION.

Plate CX has been colored to represent in a general way the character of the country. The darker color represents the area upon which forests suitable for timber have grown, while the lighter shade covers the areas within which trees fit only for firewood are to be found. The uncolored portion on the western end of the map is the high desert region, upon which there is very little, if any, forage. The rest of the basin may be considered as suitable for grazing, and in most places the soil, if watered, is excellent for farming purposes.

The total area of the timber land as shown by the map is 5,380 square miles; of the firewood, 4,820 square miles, and of the desert area, about 3,000 square miles, leaving in the basin a total of 44,120 square miles of grazing and agricultural land, this latter area being distinguished by the brownish tint. Within this are spots indicated by a dark color showing the relative location of lands under cultivation by irrigation, and along the streams mainly are strips of lighter tint, showing lands which possibly may be brought under irrigation by a thorough utilization of the water supply.

EXTENT OF IRRIGATION.

The total area upon which crops were raised by irrigation in 1889 was, as shown by the Eleventh Census, 542,602 acres. Of this amount 412,683 acres were in Colorado, 120,893 acres in Wyoming, and 9,026 acres in Nebraska. As shown by the map, Pl. CX, these areas are clustered around the base of the mountain ranges where the streams issue from the canyon or broken ground out upon the edge of the plains. There are also a few localities further down stream where water has been diverted, but these are relatively of less importance, largely on account of the fact that little dependence can be placed upon the supply of water during summer.

As a rule it may be said that wherever water can be obtained and brought out at moderate expense upon arable land this has already been done. On all of the minor streams of the basin an amount of water is claimed to exceed that which ordinarily can be found in them. Cultivation has advanced to such an extent that during the summer there is not sufficient water available to fill the demands of the farmers. The principal exception is in the case of the North Platte, where there is always a surplus of water, but which, however, can only be utilized by the construction of extensive systems of irrigation.

The basin of the Platte, especially that of the south branch of the river, contains some of the largest irrigating canals in the United States, and the development of agriculture by the artificial application of water has been brought to a state as high, if not higher, than that of any other part of the country, excepting possibly California. In Wyoming there still remain opportunities for the development of large systems of irrigation, but in Colorado canals have been built at nearly every favorable locality and the aggregate capacity of these is so great that it is improbable that they can receive water sufficient to supply all of the agricultural land which can be reached by them.

WATER MEASUREMENTS.

Measurements of the amount of water flowing at various points on the creeks and rivers of this basin have been made by the state engineers of Colorado and Wyoming, and the water supply is probably better known than that of any other area of its size. In Colorado some of these measurements and continuous computations of discharge date from 1884, and in Wyoming from 1887, thus giving in one or two instances the spring and summer discharge through eight years. The results of the work of the state engineers of Colorado are to be found in the biennial reports to the governor of the state, and those for Wyoming in part in the first and second annual report of the territorial engineer and also in the first biennial report of the state engineer. In addition to these data results of a number of gaugings are to be found in reports by Henry Gannett in the Hayden reports for 1876 and 1877,[1] and also in the annual reports of the present Geological Survey. All of these will be discussed in the following pages under the head of the various subbasins in which they were obtained.

PRECIPITATION.

In this basin and in most of those of the western half of the United States there are few records giving the monthly and annual rainfall for any considerable number of years. The Signal Service of the Army has, however brought together and published all of the data available, and from these tables the following condensed statement has been obtained.[2] The mean annual rainfall is given only for the places having the longest record, stations where observations have been carried on for one or two years only being omitted. The order given is, in general, that from west to east.

---

[1] U. S. Geol. and Geog. Survey of Colorado and adjacent territory, 1876. F. V. Hayden. Washington, 1878, pp. 311–347. Also U. S. Geol. and Geog. Survey of the territories of Idaho and Wyoming, 1877. F. V. Hayden, Washington, 1879, pp. 673–710.

[2] Irrigation and water storage in the arid regions, by Gen. A. W. Greely, chief signal officer, Ex. Doc. No. 287, House, Fifty-first Congress, second session, Washington, 1891. Climate of Nebraska, Ex. Doc. No. 115, Senate, Fifty-first Congress, first session, 1890. Rainfall on the Pacific slope, etc., Ex. Doc. No. 91, Senate, Fiftieth Congress, first session, 1888.

Locality.	Length of record.	Average depth of rainfall.
	Years.	*Inches.*
Fort Fred Steele, Wyo., 25 miles below Saratoga	12	11·03
Fort Sanders, 3 miles south of Laramie City, Wyo	9	12·92
Fort Fetterman, 8 miles above Douglas, Wyo	12	15·06
Fort Laramie, Wyo	26	12·30
Cheyenne, Wyo	20	11·68
Fort Collins, Colo	19	13·75
Golden, Colo	12	17·55
Denver, Colo	22	14·32
Colorado Springs, Colo	20	14·79
Pikes Peak, Colo	15	28·65
Fort Morgan, Colo	7	8·08
Fort Sedgwick and Julesburg, Colo	7	13·80
Sidney, Nebr	12	14·23
North Platte, Nebr	15	19·18
Fort McPherson, Nebr	13	17·66
Redwillow, Nebr	5	21·77
Fort Kearney, Nebr	17	25·44

The highest of these stations, that on Pikes peak, is at an altitude of 14,134 feet, and the lowest, Fort Kearney, Nebraska, is 2,360 feet. The other stations range from 3,000 up to 7,000 feet, as shown by the contoured map. It is evident from an inspection of the table that the mean annual precipitation over the greater part of the basin is less than 15 inches, the amount varying from about 30 inches on the summits of the mountains down to from 12 to 15 inches at their base. On going away from the mountains down the slope of the plains the mean annual rainfall decreases for some distance, and as progress is made toward the subhumid regions the quantity increases up to 20 inches or more. In other words, as is well known, the least rainfall is to be found along the western border of the Great plains at a short distance from the base of the mountains.

The distribution of rainfall by months is quite uniform over the basin, being similar in character to that prevailing in the adjoining drainage basins. By taking data given for the stations above mentioned, excepting Pikes peak, the following table has been prepared, showing the mean monthly rainfall of the localities named and the percentage that this bears to the total for the year:

	Inches.	*Per cent.*		*Inches.*	*Per cent.*
January	0·54	3·5	August	1·65	10·7
February	·56	3·6	September	1·16	7·6
March	·82	5·4	October	·93	6·1
April	1·76	11·5	November	·57	3·8
May	2·65	17·3	December	·58	3·8
June	1·90	12·4			
July	2·19	14·3	Total	15·31	100·0

UPPER NORTH PLATTE.

The North Platte river rises in the mountains partially surrounding the North park in the western end of Larimer county, Colorado, and, flowing northerly out of the park, traverses Carbon county, Wyoming, its course being a little west of north. Shortly after leaving Carbon county the river receives from the west the Sweetwater, which drains a part of the southern end of the Wind River range. Irrigation is being carried on by the utilization of nearly all of the tributaries above the Sweetwater, the water supply being comparatively large and easily available for this purpose.

The North park is at an altitude of from 7,500 feet to nearly 8,000 feet, while the mountains surrounding it rise to heights of from 12,000 to 13,000 feet above sea level. From these come almost innumerable streams tributary to one or another of the three forks which, after traversing the park converge at the lower or northern end, forming the North Platte. The surface of the park is undulating, but from an elevation appears to be quite level. The greater part is covered by native grasses, furnishing excellent grazing. The climate, however, is too cold for the general practice of agriculture. Small ditches have been dug, taking water out of the mountain streams for the purpose of irrigating forage, and according to the report of the state engineer of Colorado, over 150 of these have been recorded. The water supply is large, ample for all present needs.

At the north end of the park the Medicine Bow range on the east and the Park range on the west approach each other, the North Platte escaping through a narrow canyon between these, finally entering the broad valley. Here it receives tributaries from both mountain ranges, each stream being of value for irrigation. The general height of the farming land is a little under 7,000 feet, the altitude at Fort Steele being 6,516 feet and at Rawlins 6,754. The principal crop is hay, the cereals having a relatively small acreage.

Measurements of the amount of water available have been made by the state engineer of Wyoming, from whom have been obtained the results of various gaugings,[1] the principal of which are herewith given in geographic order. The most southerly or highest tributary measured is Brush creek, coming from the Medicine Bow range and entering the North Platte about 6 miles below the mouth of the canyon. The discharge on August 6, 1891, at Condict ranch was 34 second-feet. Below this on the opposite side are Grand Encampment and Cow creeks, the first of which on August 1 discharged 151 second-feet and the latter 14 second-feet. The next in order is South Spring creek. This on July 24, 1891, discharged at a point about 6 miles south of Saratoga 25 second-feet, and North Spring creek 15 second-feet. Jack creek westerly from Saratoga on July 17 discharged 14 second-feet, and Pass creek 20 miles north of Saratoga on June 30 discharged 46 second-feet. The water in all of these streams diminishes rapidly in July, and during August there is often scarcity.

---

[1] First biennial report of the state engineer to the governor of Wyoming, 1891 and 1892. Cheyenne, Wyo., 1892. Appendix, p. XVIII.

There are no measurements available of the amount of water in the North Platte in this part of its course, but it is known there is a large volume, and if canals can be built heading in or near the canyon and running out on each side of the valley, large tracts can be brought under irrigation. As it is at present only the lowlands along the creeks are utilized, owing to the expense involved in the construction of any comprehensive system.

The Sweetwater river, after leaving the Wind river mountains, flows in a general easterly course from Fremont county along the southern edge of Natrona county to its junction with the North Platte. This river discharges a large perennial supply of water, the amount of which is not known. Little if any irrigation is carried on along this stream, on account of the difficulty and expense of diverting the water upon the agricultural lands. The side streams, however, like those of the North Platte, are utilized wherever this can be easily done. On the broad undulating plain through which this river runs there are vast areas of fertile land lying at an altitude of a little over 6,000 feet. The soil is fertile, and were it not for the extreme aridity of the country, would be capable of producing the hardier cereals and crops of grass. It is possible that in the future canals may be built to cover some of these areas, but extensive surveys will be required before the facts can be definitely stated.

LARAMIE RIVER.

The Laramie river rises in the Medicine Bow mountains east of North park, and, flowing northerly across the State line into Wyoming, reaches the edge of the Laramie plains. From this point it turns northeasterly, crosses the plains and, as a rapid, clear stream, flows northerly near the foot of the Laramie hills through broad, grass-covered bottoms. A gauging station has been established at Woods, giving the discharge of the river as it enters upon the plains. The record kept by the State engineer of Wyoming shows that in 1889, from January to March, inclusive, the discharge was practically uniform, being about 112 second-feet. The maximum discharge, in June, was 1,620 second-feet, and the minimum, 43 second-feet, in September. A gauging on November 6, 1891, gave a discharge of 75 second-feet and on June 7, 1892, 1,571 second-feet, the mean velocity being 6·6 feet per second.

The river in its course along the Laramie plains does not receive any tributaries from the Laramie hills, and, excepting from the Little Laramie, no water enters from the creeks on the west. These latter streams, draining the Medicine Bow range, flow out upon the plains into lakes or marshes, where the water evaporates, leaving the smaller lakes at least strongly alkaline. These mountains rise to altitudes of from 3,000 to 4,000 feet above the plains, thus giving rise to large creeks, while the Laramie hills on the eastern side of the plains are relatively but low ridges, rising about 1,500 feet above the bottom lands, and the water from them flows toward the east. The Laramie plains are about 30 miles in width, and 80 miles in length from north to south, and have an average elevation of about 7,000 feet, the town of Laramie being at an altitude of 7,159 feet, according to the railroad levels. In many respects these plains, though larger, resemble the parks within the Rocky mountains. The plain with its ridges and surrounding bench lands is well covered with grass, affording excellent grazing, but owing to the climate there is little agriculture carried on, the chief industry being stock raising.

The Little Laramie river rises at about the center of Medicine Bow range, flowing easterly out upon the Laramie plains at a point west of the town of Laramie. This, as above stated, is the only stream which crosses the plains and flows into the Big Laramie. On May 28, 1891, as gauged by the state engineer, the Little Laramie at May's ranch was discharging at the rate of 562 second-feet and on June 7, 1892, at the same place, 618 second-feet. North of this is Seven Mile creek, which empties into James lake. On June 6, 1891, this was flowing at the rate of 40 second-feet, but by August 28 it was nearly or quite dry. About 3 miles further north is Four Mile creek, which on June 9, 1891, was discharging 25 second-feet. Continuing along the base of the mountains for about 8 miles Dutton creek is reached, this stream losing its water in Cooper lake. On June 12, 1891, the discharge was nearly 22 second-feet, but by the latter part of August this as well as the two creeks above named had become dry.[1] A number of ditches have been taken out of these streams, most of these being from 1 to 6 miles in length. The largest canals are those taken from Laramie river, heading at or below the canyon and continuing along the river toward the town of Laramie, one of these being over 25 miles in length. The waters of all the small streams are being utilized during the summer, and it is probable that some of the floods of spring will be saved in order to increase the acreage which can be watered during the dry season. A gauging of the amount of water in Laramie river at the town of that name was made on October 5, 1892, at which time there was found only 26 second-feet. This represents mainly the excess or seepage water from the canals covering land in the vicinity. Twenty days later the flow had increased to about 63 second-feet as shown by a measurement made by the state engineer.

After passing through or around the Laramie hills the river flows easterly out upon the Great Plains, receiving about 18 miles above its mouth Chugwater creek, which flows in from the south through a broad, fertile valley. This latter creek flows northerly along the eastern front of Laramie hills, being formed by the union of small creeks which drain this elevated land. Irrigation is carried on along the stream, the water supply being completely utilized, at least during the dry season. In the fertile valley of the Laramie are some of the finest irrigated lands of the state, producing large crops each year.

---

[1] First biennial report of the state engineer to the governor of Wyoming, 1891 and 1892. Cheyenne, Wyo., 1892. Appendix, pp. XVIII, XX.

LOWER NORTH PLATTE.

Under this heading may be included that part of the river from the mouth of the Sweetwater down to the junction of the South Platte, comparatively little water being used from the main stream, as it is difficult to divert it. There is, however, a practically unlimited amount of arable land along the river, which, except for grazing, is worthless without irrigation. The side streams, which come in mainly from the south, are completely utilized, and more land would be brought under cultivation along the course of each if water could be had. Below the Laramie river the principal tributaries are Rawhide creek and Horse creek, both of which discharge small quantities of water, except during floods. Horse creek rises in the Laramie hills, south of Chugwater, the various streams which go to make it up flowing out easterly upon the plains. On the highlands in this vicinity farming without irrigation has been attempted with some success, but no dependence can be placed upon the crops coming to maturity every year.

At about the place where the North Platte crosses into Nebraska, and at various points below this, are the headworks of large irrigating canals, some of them in operation, others in various stages of construction. These cover lands on both sides of the river, the greater number of irrigation works being, however, on the south side. In addition surveys have been made for great systems, which, if carried out, will involve the expenditure of millions of dollars. The object in view in these large schemes is to mount the bluffs bordering the bottom lands along the river and thus carry out water upon the plains. These bluffs rise abruptly to heights of 300 feet and over, so that if the project is practicable the canal lines must be very long and expensive. The soil, however, on the plains is doubtless better than that in the valley, being in places less sandy and without an excess of alkaline salts. The valley or bottom lands along the river are being brought under cultivation by irrigation, there being probably a dozen canals already in use. In this part of the Platte drainage basin, however, corn, wheat, and other cereals are usually successfully raised without the application of water.

The large amount of water available in the North Platte renders possible the successful operation of extensive systems of irrigation which can be made to cover many thousand acres of fertile bottom land even if the bluffs can not be surmounted. Measurements of the discharge of the river have been made at various points by the state engineer of Wyoming and also by topographers of the U. S. Geological

Survey. These have been mainly at Douglas, in Converse county, Wyoming, 70 miles or more above the mouth of Laramie river, also at Fairbanks, Laramie county, about 15 miles above the mouth of Laramie river, and at points in Nebraska from near the state line down to the town of North Platte, at the junction of this river with the South Platte. The following table gives the results of these measurements:

Date.	Locality.	Drainage area in square miles.	Discharge in second-feet.
June 3, 1891	Douglas, Wyo	14, 665	10, 130
Oct. 13, 1891	Fairbanks, Wyo	16, 775	579
Dec. 4, 1891	Douglas, Wyo	14, 665	807
Nov. 5, 1892	do	14, 665	595
Sept. 14, 1892	North Platte, Nebr	28, 250	770
Oct. 8, 1892	Camp Clarke, Nebr	25, 267	335
Nov. 2, 1892	North Platte, Nebr	28, 250	1, 070
Nov. 22, 1892	do	28, 250	1, 370

These gaugings show that during the latter part of the year the discharge may fall below 500 second-feet, but even with this minimum quantity canals of considerable size can be successfully operated, especially if they take water from points along the stream at distances of from 10 to 20 miles from each other. The channel of the river and the adjacent low lands are underlain by pervious sands and gravels containing large volumes of water, and even if one irrigating system takes all of the available water at a given point it is probable that at a distance of 10 miles or more below there will be found flowing a stream of considerable size due to the return of the ground water to the surface. The gaugings of this river made by Mr. A. M. Van Anken, mentioned in the preceding report,[1] doubtless give an exaggerated idea of the low-water discharge, and in the light of later official measurements are considered to be misleading. The observations of river height made by him serve, however, to illustrate the relative fluctuations of the river and are therefore given in the accompanying diagram, Fig. 57.

SOUTH PLATTE, ABOVE DENVER.

The South Platte heads behind the Front range of the Rocky mountains, its upper waters coming from the South Park,[2] which in many respects resembles the region from which come the higher tributaries of the North Platte. The Park range, rising to heights of 13,000 feet and upward, on the west and the Colorado Front range on the east receive a large amount of snow during the winter, which, melting, feeds numerous small streams flowing into the park. The altitude of the valley lands ranges from 8,000 to 10,000 feet, and, as a consequence, only a few of the hardier cereals can be raised. Various kinds of grass, however, grow luxuriantly, especially if water is applied during the dry season. Along each of the small streams, wherever ditches can be successfully located at small expense, irrigation is being carried on and large crops of hay are obtained.

---

[1] Twelfth annual report of U. S. Geol. Survey, pt. 2, Irrigation, pp. 239, 240.

[2] U. S. Geol. and Geog. Survey Terr., Hayden, 1876, pp. 323–328.

The water supply of the South park is relatively large and is freely used upon the hay lands. In a few instances the number of ditches has been so greatly increased that there is scarcity during the dry season, and it is possible that attempts will be made to obviate this by the construction of reservoirs. In view of the great and increasing deficiency of water farther down the stream it seems imperative to utilize all possible methods of saving water in these elevated regions.

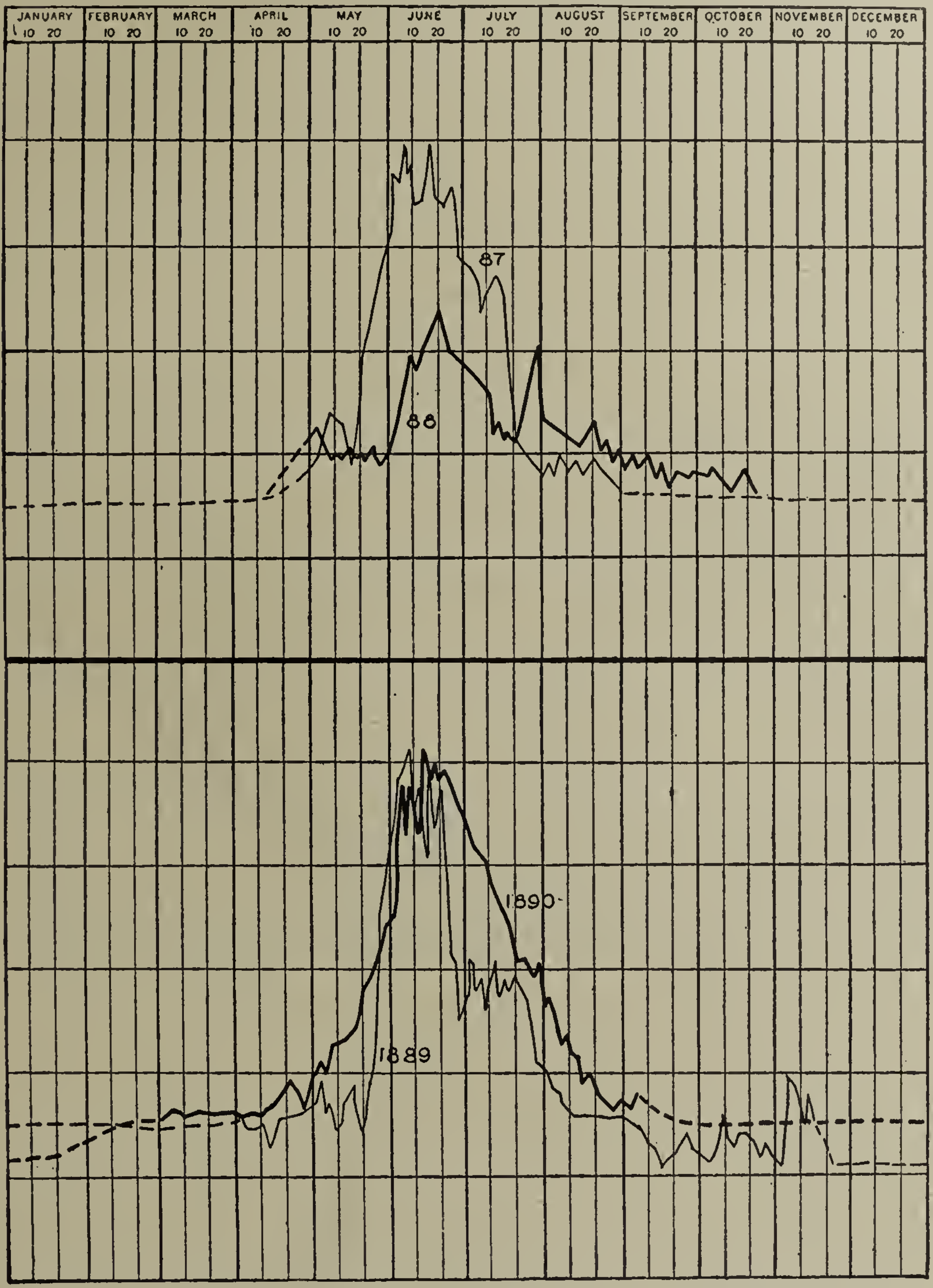


Fig. 57.—Diagram of daily fluctuations of North Platte river, Wyoming, 1887 to 1890.

The tributaries of the South Platte in the park flow in a general southeasterly direction, then turn toward the north and pass out in deep canyons through the Front range. A few measurements of these streams were made in 1876 by topographers of the Hayden survey. These show that on July 3 the Middle fork of the South Platte, at a point about 6 miles below Fairplay, discharged 388 second-feet, and at Hartzell's ranch, above the mouth of the Little Platte, on June 29, the discharge was 367 second-feet. Further down, below the mouth of Twin creek, the discharge, on June 23, was 1,015 second-feet, and at the foot of the canyon, on September 8, was 1,400 second-feet.[1] A continuous record of the height of the water flowing in the river was begun by the state engineer of Colorado[2] on July 12, 1887, at a station near Deansbury in the canyon of the river, about 26 miles above Denver, and where the drainage area is 2,600 square miles. The results of the computations of daily discharge are shown in the tables, p. 93, and are graphically given in Fig. 58.

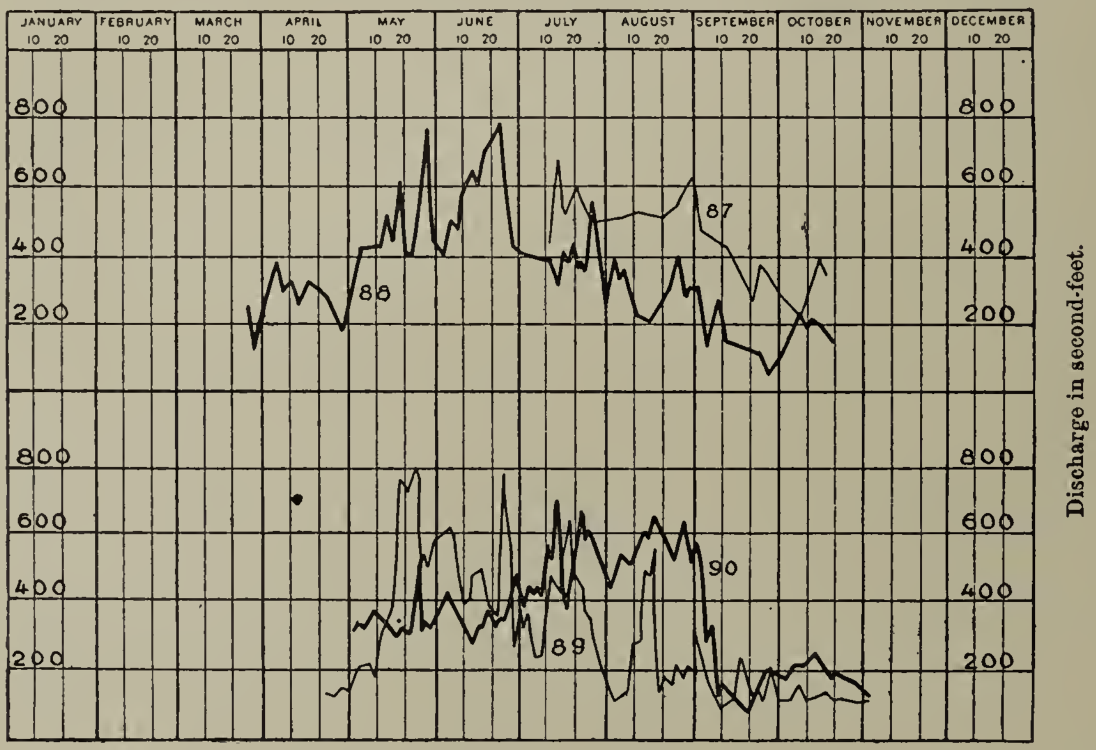


Fig. 58.—Diagram of daily discharge of South Platte river near Deansbury, Colo., 1887 to 1890.

Beginning at and below the canyon and extending down toward Denver are several canals which in size rank among the first in the United States. The most extensive of these is that of the Northern Colorado Irrigating Company, commonly known as the English High-line. This extends northeasterly from the river, covering land south and east of the city, and having a total length of 85 miles. Other canals of less size and length carry out water from the river on the same side below this and also on the western edge of the valley. In the aggregate the capacity of these canals exceeds the discharge of the river, and the question of distribution of water in the dry season becomes a matter of first importance. As a result of scarcity of water there have been losses of crops, the yield per acre being in some years one-half or one-fourth that of seasons in which water was plenty.

---

[1] U. S. Geol. and Geog. Survey Terr., Hayden, 1876, rept. of Henry Gannett, p. 324.

[2] Fourth Bien. Rept. state engineer of Colorado for 1887 and 1888, Denver, Colo., 1889, p. 63; also Fifth Bien. Rept. of same for 1891, p. 19.

Below the mouth of the canyon the principal tributaries on the west are Dear and Bear creeks and on the east Cherry creek, the latter draining a part of the relatively low divide between the Arkansas and Platte. Along each of these streams ditches and canals have been built, utilizing the available water, the capacity of the ditches being in excess of the summer flow. The discharge of Bear creek, at a point 2½ miles above Morrison, ranges from 20 to 200 second-feet, averaging about 50 second-feet, the drainage area being 141 square miles. The discharge in general follows that of the neighboring streams and a diagram of the fluctuations does not materially differ from those given for other creeks.

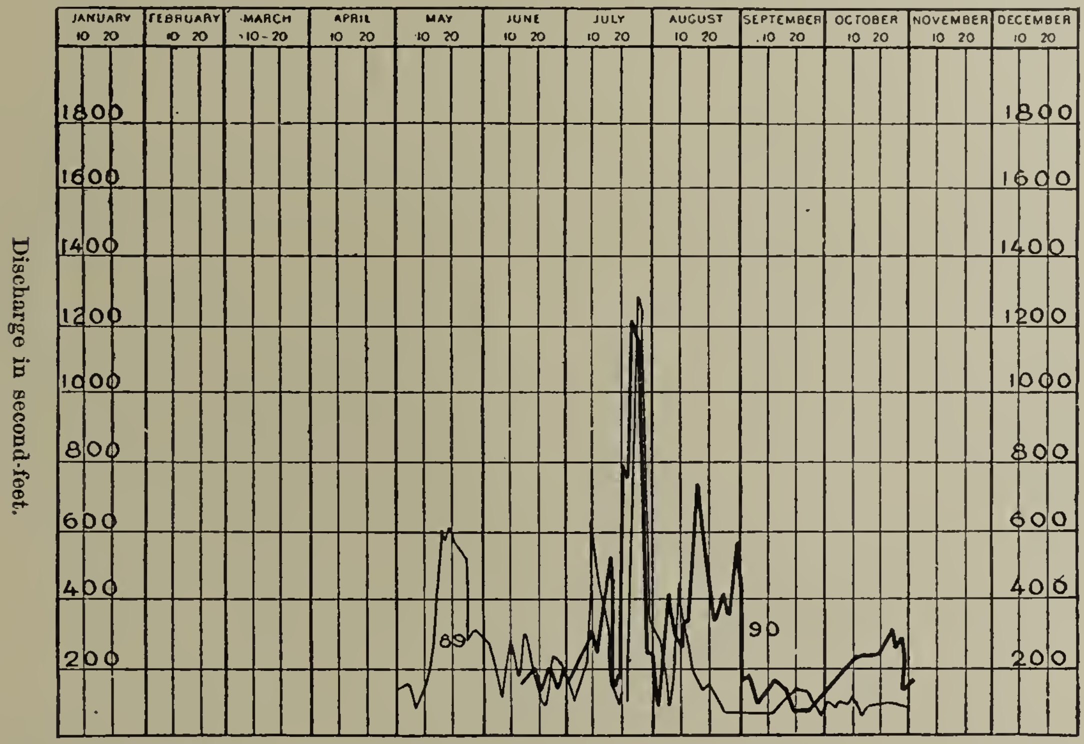


FIG. 59.—Diagram of daily discharge of South Platte river at Denver, Colorado, 1889 and 1890.

One of the earliest measurements of the amount of water in the South Platte at Denver is that made in December, 1876, giving 492 second-feet.[1] The total drainage area at this place is 3,870 square miles. A second measurement, made about 2 miles above Denver, during low water gave 204 second-feet. Computations of the daily discharge of the river at a station at the foot of Twenty-first street, Denver, have been carried on by the state engineer, the results of these being shown by Fig. 59.

---

[1] U. S. Geol. and Geog. Survey Terr. Hayden, 1876, rept of Henry Gannett, p. 324

CACHE LA POUDRE AND OTHER CREEKS.

Below Denver the South Platte gradually trends farther and farther from the mountains, and the creeks flowing into it from the west traverse a wider strip of valley land the farther they are to the north. The first stream of importance below Denver is Clear creek, and north of that in order St. Vrain creek, Thompson creek, and Cache la Poudre, the latter being the largest. Maps showing the lower courses of these streams and the canals taken from them have been published in the fourth and fifth biennnal reports of the state engineer of Colorado, and a glance at these shows the large number of canals and ditches leading out apparently in the most confusing manner. As a rule it may be said that along all these streams, as well as the main river, the aggregate capacity of the irrigating systems is so great that not all of them can receive sufficient water, and as a consequence only a portion of the cultivated lands can be thoroughly irrigated.

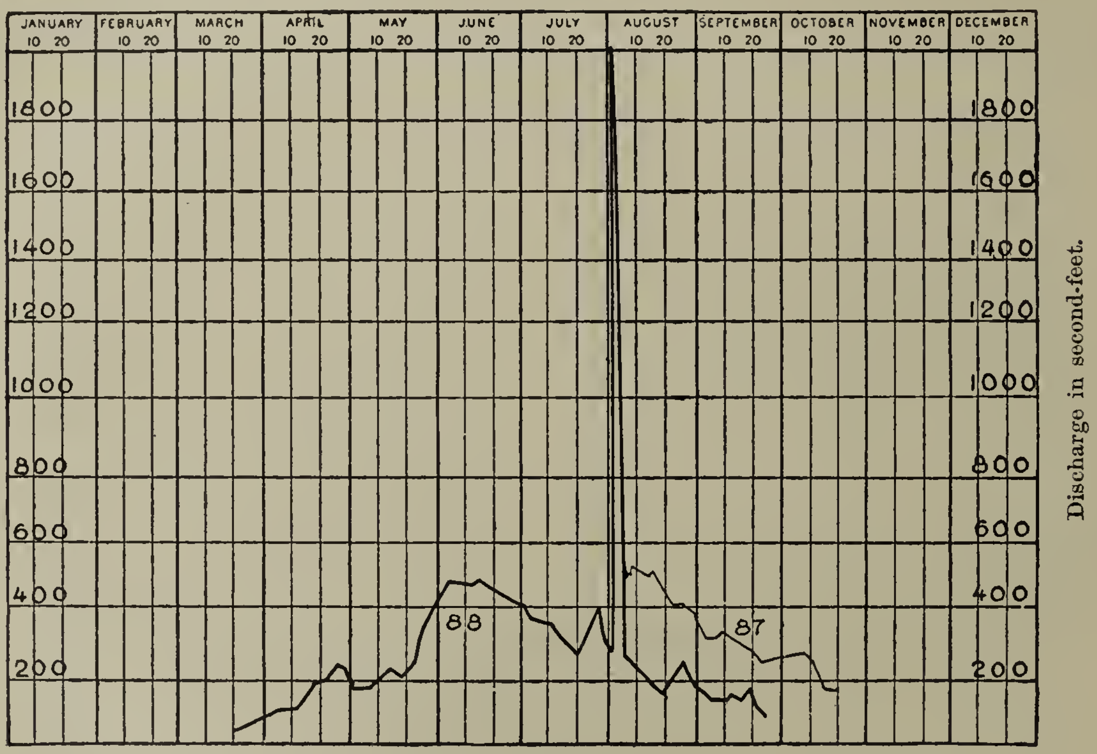


FIG. 60.—Diagram of daily discharge of Clear creek, Colorado, 1887 and 1888.

The earliest records of water measurement on Clear creek are those quoted in the Hayden report for 1876,[1] giving the flood discharge at Golden City on June 19 of 1,765 second-feet, on August 27 of 536 second-feet, and on September 3 of 374 second-feet. In August, 1887, a permanent station was established in the canyon at a point about 7 miles above Golden, being thus above the heads of irrigating ditches. The area drained is 338 square miles. From the records kept by the state engineer the diagram, Fig. 60, has been prepared, showing the daily discharge during the fall of 1887 and the greater part of 1888. The most notable feature on this plate is the great discharge on August 1, 1888, when for two hours the river flowed at the rate of 8,700 second-feet, according to the computations of the state engineer. This is typical of the extraordinary floods which may happen at any time, especially during the summer season, on almost any stream of the arid region. These short, destructive floods are caused by what are locally known as cloud-bursts, immense quantities of water being precipitated over a very small area. Floods of a similar character can be seen on many other diagrams of discharge, the relative increase of water, however, being usually less.

---

[1] U. S. Geol. and Geog. Survey Terr., Hayden, 1876, rept. of Henry Gannett, p. 325.

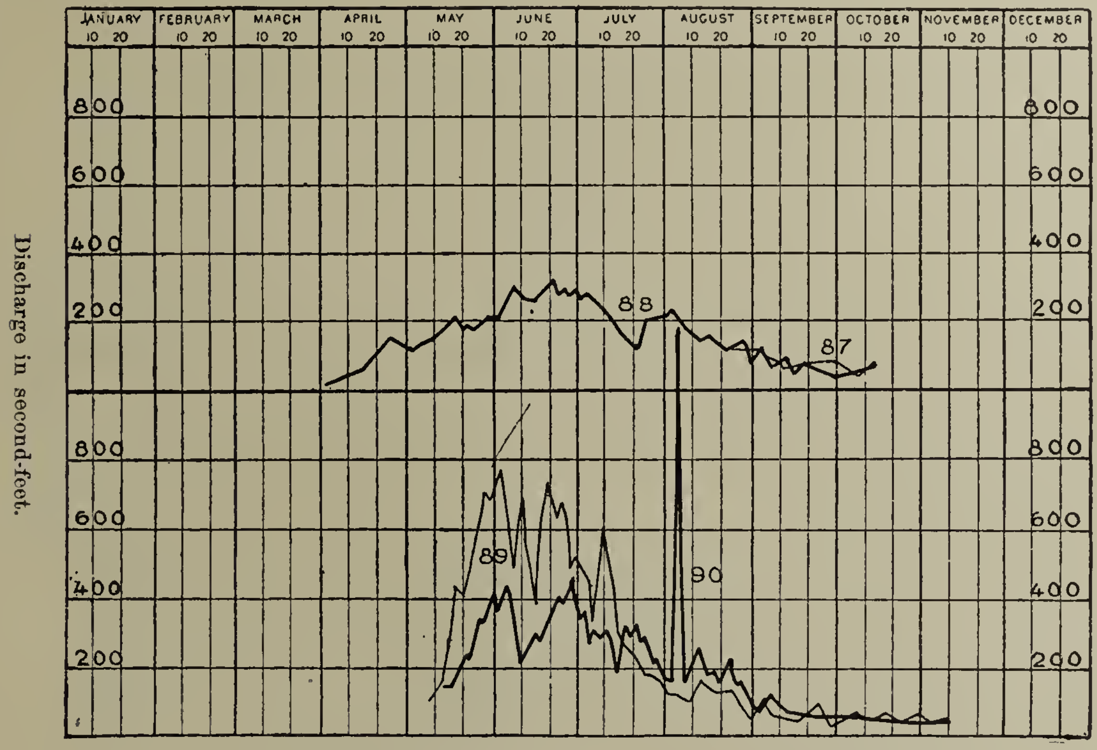


FIG. 61.—Diagram of daily discharge of North Boulder creek, Colorado, 1887 to 1890.

There are fully twenty-five canals and ditches of notable length taking water from Clear creek below the canyon, one of these, that known as the Agricultural ditch, extending around east and south of Denver, while others cover lower lands nearer the stream and follow down along the west side of the South Platte.

Boulder creek, one of the principal tributaries of St. Vrain, is the next stream of importance north of the catchment area of Clear creek. Two gauging stations have been established by the state engineer of Colorado, one on the South Boulder, the other on North Boulder, the latter being about 4 miles above the town of Boulder. The drainage area is 102 square miles. The results of the observations at this latter place are shown in Fig. 61. This exhibits among other facts a sudden flood occurring in August, 1890, at which time the discharge reached 1,200 second-feet. The diagram of discharge of the South Boulder is so similar to others given that it does not seem desirable to reproduce it. The gauging station on St. Vrain creek, established in August, 1887, is located about a quarter of a mile below Lyons at a point below the junction of the North and South forks, the area drained being 209 square miles. Results obtained at this place are shown on Fig. 62, which in most respects is similar to those previously given.

Big Thompson creek, which furnishes water for the lands in the vicinity of Loveland, is in order toward the north the next stream whose discharge has been measured. The gauging station is about 10 miles west of Loveland, being thus, as in the case of other creeks, above the heads of irrigating ditches. The drainage area above this point is 305 square miles. Fig. 63, showing the discharge for portions of the years 1887 to 1890, inclusive, has been prepared from data contained in the annual reports of the state engineer. This diagram shows a sudden flood occurring about ten days earlier in the season than that on Boulder creek. These floods, although not discharging what would be considered a large amount of water if distributed during several days, come with such sudden violence that they often carry out bridges and the head works of canals, resulting in loss to the farmers, from the fact that before repairs of irrigation works can be made a large part of the crops may be withered or completely burned by the heat of the sun.

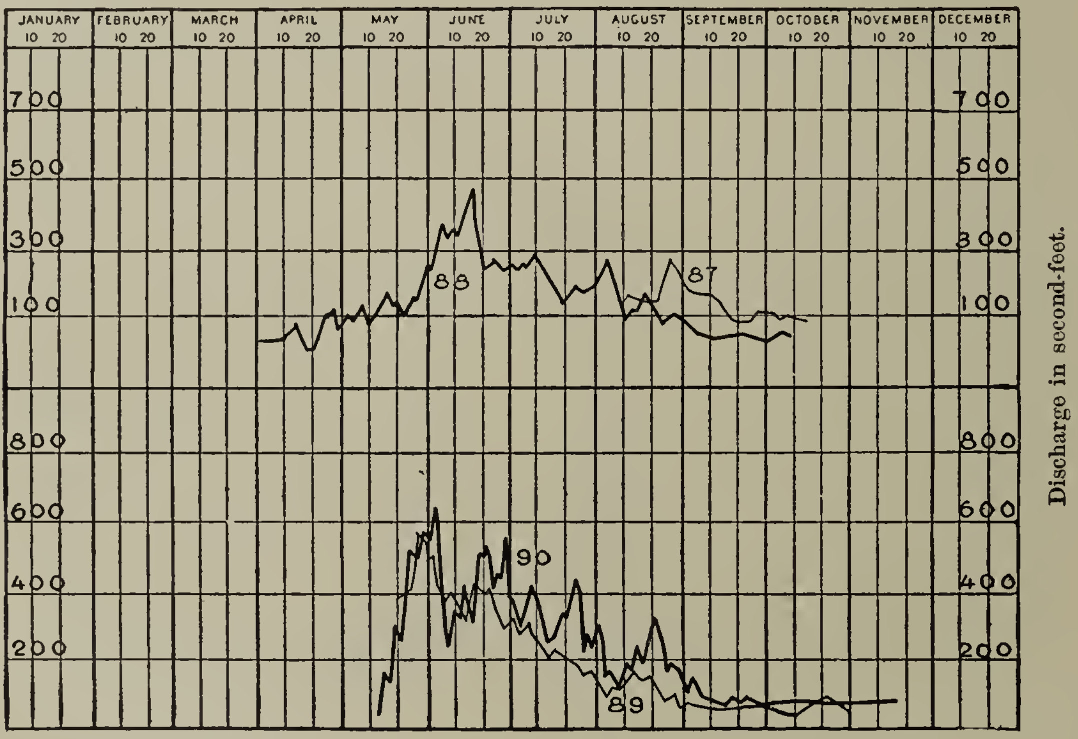


FIG. 62.—Diagram of daily discharge of St. Vrain creek, Colorado, 1887 to 1890.

Cache la Poudre creek is the lowest or most northerly important tributary of the South Platte. The point at which it enters the main river is marked by an abrupt change in direction, the river, which up to this place has been flowing in a general way toward the north, turning toward the east in its course across the Great Plains. Cache la Poudre creek receives its waters mainly from the eastern side of the Colorado Park range, some of its tributaries rising near the headwaters of the North Platte and Laramie. It also receives small streams from the eastern slope of the Laramie hills not far from Cheyenne. The water measurements on this creek have been made at a place about a half mile above the mouth of the canyon and 12 miles above Fort Collins, being below the junction of the North and South forks. The discharge at this locality from 1884 to 1890 is shown graphically on Pl. LXV of the twelfth annual report.[1] From this creek are taken large canals, covering land in the vicinity of Fort Collins and Greeley, the latter place being the locality where systematic irrigation on a large scale was first tried in the state.

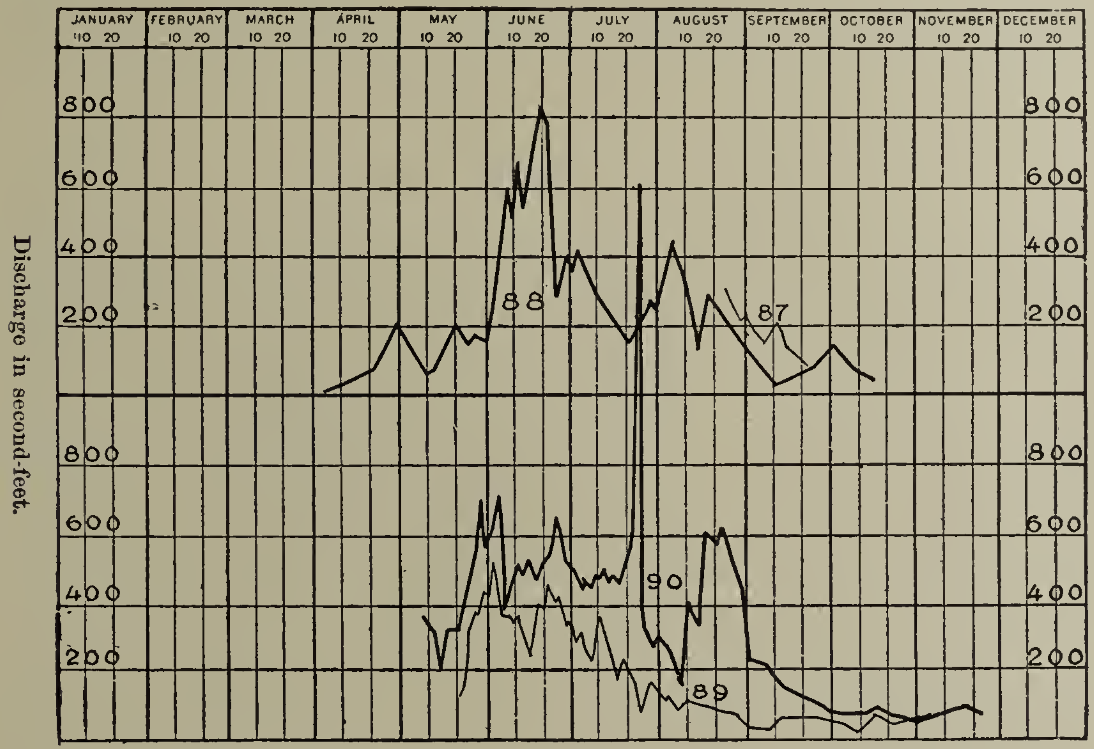


FIG. 63.—Diagram of daily discharge of Big Thompson creek, Colorado, 1887 to 1890.

Besides the canals and ditches taking water from these streams there are a number along the South Platte itself, utilizing the supply which escapes into the river as surplus or seepage. The head works of these are located at distances of from 1 to 5 miles from each other, and although at one place the channel may be almost dry, yet at some distance below there is sufficient water to partly fill at least one or other of the ditches. Crops can rarely be produced without irrigation in this part of the Platte basin, about the only exceptions being bottom lands kept moist by seepage from canals above them. In a few instances these lower lands receive such a quantity of seepage water that they have been converted into meadows or even into marshes.

The development of irrigation and the rapid increase of area under cultivation have taken place to an entent such that, as previously stated, the water supply is inadequate to fill the demands made upon it. As a method of relief the farmers have undertaken the construction of reservoirs near the foothills, storing some of the flood waters of spring. The feasibility of larger systems of this kind in the parks and small valleys among the mountains has been often discussed, and movements are slowly being made toward the realization of storage projects. There are, however, many difficulties surrounding the construction of suitable retaining walls and the recovery and distribution of the waters, which as a matter of course must be brought down to the canals below in the channel of the stream, and in many cases past the head works of a large number of irrigating ditches. Without such methods of increasing the summer flow of the stream there can be little hope of extending the irrigated acreage except by more careful methods of applying water to the soil and by greater thoroughness in all other agricultural operations.

---

[1] Twelfth Ann. Rep. U. S. Geol. Surv., part 2, Irrigation, p. 238.

SOUTH PLATTE BELOW GREELEY.

After leaving the junction of the Cache la Poudre the South Platte flows eastward and then northeasterly through arid plains toward the subhumid regions. In the eastern end of the basin near the junction with the North Platte, the rainfall is sufficient for many of the cereals if these are properly cultivated. Irrigation, however, is essential for the production of vegetables and fruit, especially on the lower grounds, and even in rainy years can be profitably employed by the farmer. Developments in this direction, however, have been retarded by the scarcity of water, the difficulty of diverting it, and the fact that the settlers can often make a living by what is called "dry farming."

In eastern Colorado the South Platte is often dry during the summer, there being, however, a small amount of water seeping through the bed. Irrigating ditches have been taken out on both sides in Weld, Morgan, and Logan counties, irrigating lands near the stream. These obtain ample water only during spring floods, and having once saturated the land can obtain little or no more during the summer. This one watering under favorable circumstances may suffice, but there is danger of loss of crops later on. The streams which flow into this part of the river are usually dry and at times become torrents, so that it is almost impossible to utilize this irregular supply.

On the highlands drained by streams flowing from the north or from the south agriculture has been attempted, but owing to the scarcity of rainfall has not been on the whole successful. Stock-raising is still and probably will be the principal industry. A few farmers, coming without experience in methods adapted to a dry country, have tried year after year to raise a crop, but without success, and finally, having lost everything, have been compelled to go elsewhere. There is bitter complaint that in the past unscrupulous persons have taken advantage of eastern farmers and have induced communities or colonies to settle upon lands absolutely arid and without means of water supply, or have built extensive canals in the river valley, selling water rights which are practically valueless.

A few irrigating ditches have been dug along the South Platte in the vicinity of Ogallala, Nebraska. These receive water at the time of the spring floods, but during the summer the channel is usually dry and no water can be obtained except that which seeps from the pervious beds, an amount too small to be of any considerable value. As previously mentioned, hopes have been entertained that by means of deep drains extending above the heads of these ditches a large amount of ground water could be had at all times. Large sums of money have been expended in the construction of these so-called underflow canals, but the quantity of water obtained has at best been small relative to the expense incurred.

Much of the land in the vicinity of the town of North Platte is irrigated by a ditch from North Platte river, covering the long, narrow area between the north and south rivers. This locality may be considered as the most easterly in the Platte basin at which irrigation is regularly practiced. Further to the east, in the vicinity of Gothenburg and Kearney, are canals constructed for water power, from which it is proposed to obtain some water for irrigation, but the development of this method of agriculture in a relatively humid region is usually slow. In this, the western, part of Nebraska there are a number of streams which will undoubtedly be used at some future time for irrigation, especially after the results obtained along the North Platte are more widely known and appreciated. Most of these creeks and small rivers flow throughout the year, being fed by springs. On the north side of the North Platte in Nebraska are several such streams tributary to the river and so situated as to have many natural advantages for easy diversion of the water. Among the most important of these are Blue and Birdwood creeks, both of these being remarkable for the uniformity of discharge throughout the year. The quantity of water in Blue creek was measured on November 5, 1892, and found to be 105 second-feet. Birdwood creek on September 24, 1892, was discharging at the rate of 126 second-feet. Besides these mentioned are other creeks of smaller size, having a low water flow of from 3 to 5 second-feet.

TABLES OF MEAN MONTHLY AND ANNUAL DISCHARGE.

These tables give in cubic feet per second the average discharge by months of the principal streams measured by this Survey. Some of these figures have already appeared in connection with other data. The arrangement is that generally adopted in this report, beginning with the head waters of the Missouri and taking the various streams in their order toward the south, then those in the Rio Grande and Interior basins, and finally the rivers flowing into the Pacific ocean. There are also included a few computations of monthly discharge made from data obtained by the state engineer of Colorado.

The following symbols are used to denote that the observations have not been continued throughout the month: (*a*) Observations on twenty days and upwards. (*b*) Observations on from ten to nineteen days. (*c*) Observations during less than ten days.

WEST GALLATIN RIVER.

[Gauging station below mouth of Spanish creek, about 20 miles southwesterly from Bozeman, Montana. Drainage area, 850 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec. ft.*
1889	......	......	......	......	......	......	......	(*b*) 426	450	402	*400	*400	....
1890	*320	*320	(*c*) 320	460	2,092	2,641	1,388	761	607	591	506	*450	871
1891	*400	*400	*450	*500	1,897	2,516	1,534	761	583	587	501	434	880
1892	430	429	400	*450	1,488	4,163	2,544	957	734	743	589	549	1,123
Means	383	383	390	470	1,825	3,106	1,488	726	593	580	499	459	908

MADISON RIVER.

[Gauging station below Hot Springs creek, 4 miles from Red Bluff, Montana. Drainage area, 2,085 square miles.]

1890	*1,200	*1,200	*1,200	*a*1,620	4,823	4,977	2,518	1,535	1,466	1,498	1,380	1,400	2,068
1891	1,406	1,436	1,631	1,774	3,389	4,167	2,045	1,429	1,309	1,351	1,400	1,137	1,872
1892	1,305	1,504	1,488	1,295	1,454	4,900	3,225	1,519	1,360	1,327	1,424	1,324	1,844
Means	1,303	1,380	1,439	1,563	3,222	4,681	2,596	1,494	1,378	1,392	1,401	1,287	1,928

MISSOURI RIVER.

[Gauging station during 1889 at Canyon ferry, Montana; drainage area, 15,036 square miles. Gauging station during 1890 and 1891 at Craig, Montana; drainage area, 17,615 square miles.]

1889	......	......	......	......	......	......	......	......	1,873	2,230	2,502	*2,500	....
1890	*3,000	*3,000	*3,000	*b*4,662	10,472	10,074	5,020	2,216	2,232	2,379	2,868	2,763	4,307
1891	2,967	*3,500	*4,000	5,794	9.015	13,645	9,115	4,415	3,078	3,511	3,802	*3,200	5,503
Means	2,983	3.250	3,500	5,228	9,743	11,859	7.067	3,315	2,394	2,706	3,057	2,821	5,229

*Estimated.

SUN RIVER.

[Gauging station at Augusta, Montana. Drainage area, 1,175 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual May to October.
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*
1889	......	......	......	......	......	......	......	(*a*)213	214	200	191	* 175	... ...
1890	* 175	* 175	* 175	371	2,804	2,342	961	371	304	315	322	267	715
Means	175	175	175	371	2,804	2,342	961	292	259	257	256	221	691

YELLOWSTONE RIVER.

[Gauging station at Horr, Montana, 4 miles below Cinnabar. Drainage area, 2,700 square miles.]

1889	......	......	......	......	......	......	......	*b*1,660	1,270	976	743	*650	....
1890	*550	*550	*b* 585	1,417	7,522	10,086	7,682	4,375	2,276	1,473	970	695	3,181
1891	488	*500	316	1,086	5,227	7,592	6,135	3,442	1,641	1,264	891	475	2,421
1892	*500	570	713	664	3,544	11,201	10,180	4,931	2,808	1,555	952	*800	3,202
Means	512	540	538	1,054	5,431	9,625	7,999	3,600	1,999	1,316	889	655	2,846

SOUTH PLATTE RIVER.

[Gauging[1] station at Deansbury, Colorado, below junction of north and south branches. Drainage area, 2,600 square miles.]

1887	......	......	......	......	......	......	*550	550	394	*200	......	......	....
1888	......	......	*250	295	487	552	311	262	179	*150	......	......	323
1889	......	......	......	*175	478	460	324	211	129	180	......	......	297
1890	......	......	......	......	391	403	520	562	196	172	......	......	374
Means	......	......	250	235	452	471	426	396	224	175	......	......	329

NORTH BOULDER CREEK.

[Gauging[1] station 4 miles above Boulder, Colorado. Drainage area, 102 square miles.]

1887	......	......	......	.....	......	......	......	*110	80	*60	......	......	....
1888	......	......	......	81	164	261	210	157	80	*60	......	......	155
1889	......	......	......	......	*400	565	277	97	34	36	......	......	235
1890	......	......	......	......	*250	341	258	173	56	33	......	......	185
Means	......	......	......	81	271	389	248	134	62	47	......	......	176

ST. VRAIN CREEK.

[Gauging[1] station one-fourth mile below Lyons, Colorado. Drainage area, 209 square miles.]

1887	......	......	......	......	......	......	......	*150	109	*70	......	......	109
1888	......	......	......	72	156	320	208	133	56	*50	......	......	153
1889	......	......	......	......	*400	371	197	102	44	39	......	......	192
1890	......	......	......	......	*300	436	292	179	66	45	......	......	219
Means	......	......	......	72	285	375	232	141	68	51	......	......	175

BIG THOMPSON CREEK.

[Gauging[1] station 10 miles west of Loveland, Colorado. Drainage area, 305 square miles.]

1888	......	......	......	62	132	458	275	190	75	*50	......	......	196
1889	......	......	......	......	*250	382	200	89	49	46	......	......	169
1890	......	......	......	......	*400	530	454	393	151	67	......	......	332
Means	......	......	......	62	260	456	309	224	91	54	......	......	208

* Estimated.

[1] Data from state engineer of Colorado.

CACHE LA POUDRE CREEK.

[Gauging station[1] at Fort Collins, Colorado. Drainage area, 1,060 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*
1884	......	......	*b*67	219	2,537	4,812	2,144	792	305	*b*205	......	......	......
1885	......	......	......	*a*447	1,419	2,910	1,857	656	273	*b*203	......	......	......
1886	......	......	......	*c*405	1.309	1,875	717	338	185	129	......	......	......
1887	......	......	......	*200	*b*1,822	*b*1,401	735	307	175	*120	......	......	......
1888	......	......	......	181	483	1,113	420	213	109	*90	......	......	......
1889	151	106	46	113	649	1,338	514	187	67	69	88	64	283
1890	82	79	85	200	1,044	1.280	649	287	103	80	61	70	335
1891	92	79	59	144	1,221	1,900	541	228	138	118	83	79	390
1892	64	119	80	*100	*250	1,512	741	*200	......	......	......	......	......
Means	97	96	69	223	1,193	2,016	924	357	169	127	78	71	452

ARKANSAS RIVER.

[Gauging station[1] at Canyon city, Colorado. Drainage area, 3,060 square miles.]

1888	*400	*500	*600	1,000	1,440	2,090	1,350	932	605	*500	*500	*400	860
1889	*300	*300	*300	300	600	1,374	602	340	220	223	299	335	433
1890	310	363	320	477	2,090	2,611	1,571	670	519	531	522	502	874
1891	431	474	586	857	2 012	3,291	1,468	951	473	624	498	476	1,012
1892	496	493	524	522	1,241	2,787	1,798	769	435	511	527	561	889
Means	387	426	466	631	1,477	2,430	1,357	732	450	477	469	455	813

[Gauging station[1] at Pueblo, Colorado. Drainage area, 4,600 square miles.]

1885	......	......	......	......	1,069	3,187	......	......	......	......	......	......	......
1886	*400	*500	*600	*800	3,046	5,569	1,724	1,481	1.372	*800	*600	*400	1,441
1887	*400	*400	*500	*600	*2,500	3,477	3,352	1,717	1,129	*800	*600	*400	1,323
Means	400	450	550	700	2,205	4,078	2,538	1,599	1,250	800	600	400	1,298

RIO GRANDE.

[Gauging station[1] at Del Norte, Colorado. Drainage area, 1,400 square miles.]

1889	......	......	......	......	......	......	......	......	......	278	319	281	......
1890	552	796	487	913	4,331	3,807	1,515	612	383	470	478	565	1,242
1891	990	1,294	1,280	1,410	3,285	4,146	1,693	663	527	844	374	*325	1,403
1892	*300	*300	316	1,047	2,605	2,187	740	444	262	259	360	922	812
Means	614	797	661	1,123	3,407	3,379	1,316	573	391	463	382	523	1,135

[Gauging station[1] at Embudo, New Mexico. Drainage area, 7,000 square miles.]

1889	431	473	784	2,261	3,430	2,922	471	206	212	283	366	542	1,032
1890	437	553	682	2,083	4,960	4,107	1,593	814	545	562	616	648	1,467
1891	586	616	917	2,370	5,965	5,040	2,356	933	469	1,681	778	553	1,855
1892	497	596	1,051	2.979	4,890	3,146	538	191	152	202	317	324	1,240
Means	488	559	858	2,423	4,811	3,804	1,239	536	345	682	520	517	1,399

[Gauging station[1] at El Paso, Texas. Drainage area, 30,000 square miles.]

1889	......	......	......	......	3,116	2,638	237	......	......	......	......	71	......
1890	196	290	424	2,190	5,771	4,404	854	734	176	65	284	535	1,327
1891	451	809	1,866	4,265	11,852	6,714	2,271	662	768	1,488	341	344	2,653
1892	326	476	752	3,147	7,093	2,943	668	13	......	......	......	......	1,285
Means	324	525	1,014	3,201	6,958	4,175	1,008	352	236	388	156	238	1,548

---

* Estimated.

[1] Data in part from state engineer of Colorado.

GILA RIVER.

[Gauging station at Buttes, Arizona. Drainage area, 13,750 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*
1889	......	......	......	......	......	......	......	115	128	157	212	275	......
1890	680	578	387	238	87	28	130	3,137	......	......	......	......	......
Means	680	578	387	238	87	28	130	1,626	128	157	212	275	377

SALT RIVER.

[Gauging station[1] at Arizona dam, Arizona. Drainage area, 12,260 square miles.]

1888	......	......	......	......	......	......	......	*350	*350	331	842	6,698	......
1889	5,947	2,605	8,745	3,975	1,039	470	495	417	521	440	576	5,686	2,576
1890	4,982	10,097	6,421	1,840	914	511	524	3,885	2,339	2,768	4,717	6,259	3,771
Means	5,465	6,351	7,583	2,908	977	491	510	1,551	1,070	1,179	2,045	6,214	3,074

PROSSER CREEK.

[Gauging station at Boca, California. Drainage area, 55 square miles.]

1889	......	......	......	*100	259	110	17	3	2	......	......	......	......
1890	......	......	......	340	817	580	382	102	57	42	38	......	......
Means	......	......	......	220	538	345	200	53	30	42	38	......	183

LITTLE TRUCKEE RIVER.

[Gauging station at Boca, California. Drainage area, 186 square miles.]

1890	......	......	......	958	1,998	1,491	749	200	97	86	......	......	......

TRUCKEE RIVER.

[Gauging station at Boca, California. Drainage area, 887 square miles.]

1890	......	......	637	2,751	5,275	4,291	1,870	736	513	555	......	......	......

[Gauging station at Vista, Nevada. Drainage area, 1,519 square miles.]

1890	......	......	......	4,496	5,990	4,162	2,198	952	682	742	765	750	......
1891	*700	*650	*650	1,523	2,765	1,905	945	485	558	561	503	508	980
1892	593	505	723	854	937	......	......	......	......	......	......	......	......
Means	647	578	687	2,291	3,231	3,034	1,572	719	620	652	634	629	1,275

EAST CARSON RIVER.

[Gauging station at Rodenbah, Nevada. Drainage area, 414 square miles.]

1890	......	......	......	1,026	2,654	2,430	1,789	597	415	386	384	379	......
1891	388	402	783	452	1,445	1,328	618	408	388	385	385	438	619
1892	390	388	422	478	1,226	1,158	506	413	414	416	414	1,097	610
Means	389	395	603	652	1,775	1,639	971	473	406	396	395	638	728

* Estimated.

[1] Data from Samuel A. Davis, C. E., Phœnix, Oregon.

WEST CARSON RIVER.

[Gauging station at Woodfords, California. Drainage area, 70 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec. ft.*
1890	......	......	......	284	657	614	380	135	75	67	49	53	....
1891	52	48	61	127	534	338	130	65	41	48	43	47	128
1892	45	46	65	......	......	......	......	......	......	......	......	......	....
Means	49	47	63	206	596	476	255	100	58	58	46	50	167

BEAR RIVER.

[Gauging station at Battle Creek, Idaho. Drainage area, 4,500 square miles.]

1889	......	......	......	......	......	......	......	......	......	355	487	565	....
1890	875	809	1, 271	2, 978	5, 199	4, 074	1, 582	1, 000	843	854	783	748	1, 751
1891	690	780	790	1, 623	2, 652	2, 245	1, 288	835	798	980	957	1, 053	1, 224
1892	800	855	1, 304	1, 824	2, 710	4, 446	2, 345	1, 025	793	780	687	880	1, 537
Means	788	815	1, 122	2, 142	3, 520	3, 588	1. 738	954	812	742	728	812	1, 480

[Gauging station at Collinston, Utah. Drainage area, 6,000 square miles.]

1889	......	......	......	......	......	*800	362	417	509	728	848	1, 395	....
1890	*1, 500	*1, 000	3, 188	4, 953	7, 924	6, 234	3, 250	1, 754	1, 344	1, 544	1, 403	1, 243	2, 945
1891	1, 000	1, 308	1, 766	2, 729	4, 569	3, 595	1, 562	938	986	1, 235	1, 262	1, 216	1, 847
1892	1, 202	1, 209	2, 037	2, 397	3, 869	5, 660	3, 037	1. 195	1, 000	1, 131	1, 195	1, 235	2, 097
Means	1, 234	1, 172	2, 330	3, 360	5, 454	4, 072	2, 051	1, 076	960	1, 135	1, 180	1, 272	2, 108

OGDEN RIVER.

[Gauging station at Powder Mills, Utah. Drainage area, 360 square miles.]

1889	......	......	......	......	......	......	......	50	52	89	105	421	....
1890	382	680	978	1, 449	1, 818	910	458	312	206	265	255	*240	663
Means	382	680	978	1, 449	1, 818	910	458	181	129	177	180	331	639

WEBER RIVER.

[Gauging station at Uinta, Utah. Drainage area, 1,600 square miles.]

1889	......	......	......	......	......	......	......	......	......	181	208	430	....
1890	457	547	1, 091	2, 184	4, 528	2, 017	549	280	265	331	298	290	1, 070
1891	303	461	625	1, 502	2, 752	1, 621	844	338	402	599	573	534	880
1892	599	695	800	900	2, 705	2, 867	819	239	187	240	357	476	907
Means	453	568	839	1, 529	3, 328	2, 168	738	286	285	338	359	432	944

AMERICAN FORK.

[Gauging station at bridge above town of American Fork, Utah. Drainage area, 66 square miles.]

1889	......	......	......	......	......	......	......	38	30	33	30	67	....
1890	62	72	117	*380	*666	*208	*45	......	......	......	......	......	....
Means	62	72	117	380	666	208	45	38	30	33	30	67	146

* Estimated.

PROVO RIVER.

[Gauging station in canyon above Provo, Utah. Drainage area, 640 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec. ft.*
1889	......	......	......	......	......	......	150	145	150	180	224	384	....
1890	305	377	519	840	1, 926	1, 184	314	252	244	304	303	293	572
1891	255	311	492	478	1, 226	1, 190	423	260	314	364	380	343	503
1892	330	351	361	377	1, 079	1, 511	441	201	201	241	279	257	469
Means	296	346	457	565	1, 410	1, 295	332	215	227	272	296	319	503

SPANISH FORK.

[Gauging station at canyon above town of Spanish Fork, Utah. Drainage area, 670 square miles.]

1889	......	......	......	......	......	......	......	......	50	62	53	67	....
1890	68	76	143	387	777	205	114	64	63	64	50	50	172
Means	68	76	143	387	777	205	114	64	57	63	52	59	172

SEVIER RIVER.

[Gauging station at Leamington, Utah. Drainage area, 5,595 square miles.]

1889	......	......	......	......	......	......	......	48	53	111	274	395	....
1890	625	713	630	726	1, 705	1, 250	346	153	157	310	373	509	625
1891	735	772	618	503	1, 114	952	297	195	175	202	312	551	535
1892	1, 016	931	738	232	250	718	88	53	49	53	117	570	401
Means	792	805	662	487	1, 023	973	244	112	108	169	269	506	513

HENRY FORK.

[Gauging station at ferry, 1 mile above mouth Falls river, Idaho. Drainage area, 931 square miles.]

1890	1, 200	1, 250	1, 300	1, 875	4, 580	2, 270	1, 550	1, 450	3, 314	1, 280	1, 280	1, 280	1, 719
1891	1. 280	1. 280	1, 280	1, 516	2, 184	1, 801	......	......	......	......	......	......	....
Means	1, 240	1, 265	1, 290	1, 696	3, 382	2, 036	1, 550	1, 450	1, 314	1, 280	1, 280	1, 280	1, 589

FALLS RIVER.

[Gauging station at canyon, 5 miles above mouth of river, Idaho. Drainage area, 594 square miles.]

1890	......	......	......	1, 730	3, 342	2, 706	1, 669	971	774	660	541	520	....
1891	509	450	450	606	1, 765	1, 681	1, 131	607	520	520	520	520	773
Means	509	450	450	1, 168	2, 554	2, 194	1, 400	789	647	590	531	520	984

TETON RIVER.

[Gauging station at Chase's ranch, near Eerry, Idaho. Drainage area, 967 square miles.]

1890	......	......	......	740	2, 730	2, 812	2, 130	678	462	475	450	459	....
1891	400	465	450	630	1, 402	1, 661	1, 050	547	450	444	*425	*425	696
1892	*400	*425	450	575	1, 911	3, 845	2. 780	758	488	471	450	*450	1, 084
Means	400	445	450	648	2, 014	2, 773	1, 987	661	467	464	442	445	933

SNAKE RIVER.

[Gauging station at Idaho Falls, formerly known as Eagle Rock, Idaho. Drainage area, 10,100 square miles.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	Sec.ft.	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec.ft.*	*Sec. ft.*
1889	......	......	......	......	......	......	5, 184	2, 594	2, 300	2, 425	2, 737	2, 601	....
1890	*2, 000	*2, 000	2, 000	5, 702	35, 606	34, 870	19, 970	7, 875	4, 934	4, 552	4, 207	3, 900	10, 635
1892	*3, 000	*3, 000	3, 900	3, 760	18, 187	41, 357	24, 069	6, 463	4, 312	4, 156	4, 100	*4, 000	10, 025
Means	2, 500	2, 500	2, 950	4, 731	26, 897	38, 114	16, 374	5, 977	3, 849	3, 711	3, 681	3, 500	9, 565

OWYHEE RIVER.

[Gauging station at Rigsby, near Ontario, Oregon. Drainage area, 9,875 square miles.]

1890	......	......	6, 140	6, 558	5, 913	1, 403	343	179	170	170	221	309	....
1891	360	932	3, 313	4, 984	3, 114	1, 267	448	232	317	325	376	320	1, 332
1892	320	1, 250	3, 900	13, 466	13, 082	2, 980	948	594	506	570	783	800	3, 268
Means	340	1, 091	4, 451	8, 336	7, 362	1, 883	580	335	331	355	460	476	2, 162

MALHEUR RIVER.

[Gauging station at Vale, Oregon. Drainage area, 9,900 square miles.]

1890	......	......	2, 912	2, 770	1, 627	254	43	17	15	44	118	83	....
1891	88	319	703	511	217	78	30	26	23	......	......	......	....
Means	88	319	1, 808	1, 641	922	166	37	22	19	44	118	83	439

WEISER RIVER.

[Gauging station at canyon above town of Weiser, Idaho. Drainage area, 1,670 square miles.]

1890	......	......	5, 773	4, 792	4, 882	1, 792	590	138	103	166	222	396	....
1891	292	678	2, 855	1, 777	1, 331	703	......	......	......	......	......	......	....
Means	292	678	4, 314	3, 285	3, 107	1, 248	590	138	103	166	222	396	1, 228

ANNUAL DISCHARGE.

River.	Year ending—	Discharge.			Total for year.	Drainage area.	Run off.	
		Maximum.	Minimum.	Mean.			Depth.	Per square mile.
		Sec. feet.	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Sq. miles.*	*Inches.*	*Sec. ft.*
West Gallatin	Dec., 1890	3, 800	320	871	630, 604	850	14·0	1·03
	Dec., 1891	2, 975	370	880	637, 120	....	14·0	1·03
	Dec., 1892	6, 800	400	1, 123	815, 253	....	18·0	1·32
Madison	Dec., 1890	6, 420	1, 285	2, 068	1, 494, 513	2, 085	13·4	·99
	Dec., 1891	4, 620	1, 070	1, 872	1, 354, 328	....	12·2	·90
	Dec., 1892	5, 940	1, 240	1, 844	1, 338, 670	....	12·0	·88
Red Rock	Dec., 1890	675	40	148	107, 249	1, 330	1·5	·11
Missouri	Dec., 1890	12, 500	1, 742	4, 307	3, 118, 268	17, 615	3·3	·24
	Dec., 1891	16, 355	1, 742	5, 503	3, 984, 272	....	4·4	·31
Sun	Dec., 1890	4, 085	160	715	517, 676	1, 175	8·2	·61
Yellowstone	Dec., 1890	11, 915	510	3, 181	2, 303, 044	2, 700	16·0	1·18
	Dec., 1891	8, 975	285	2, 421	1, 752, 804	....	12·2	·90
	Dec., 1892	15, 500	590	3, 202	2, 324, 524	....	16·2	1·19
Cache la Poudre	Dec., 1889	1, 960	33	283	204, 868	1, 060	3·6	·27
	Dec., 1890	1, 804	37	335	242, 540	....	4·3	·33
	Dec., 1891	5, 060	32	390	283, 124	....	5·0	·37

ANNUAL DISCHARGE—Continued.

River.	Year ending—	Discharge.			Total for year.	Drainage area.	Run off.	
		Maximum.	Minimum.	Mean.			Depth.	Per square mile.
		Sec. feet.	*Sec. feet.*	*Sec. feet.*	*Acre-feet.*	*Sq. miles.*	*Inches.*	*Sec. ft.*
Arkansas at Canyon City	Dec., 1888	2, 760	430	860	622, 640	3, 060	3·8	·28
	Dec., 1889	2, 620	190	433	313, 492	....	1·9	·14
	Dec., 1890	3, 270	180	874	632, 776	....	3·9	·29
	Dec., 1891	4, 230	325	1, 012	732, 688	....	4·5	·33
	Dec., 1892	4, 750	345	889	645, 378	....	4·0	·29
Arkansas at Pueblo	Dec., 1886	7, 659	400	1, 441	1, 043, 284	4, 600	4·2	·31
	Dec., 1887	6, 510	400	1, 323	957, 852	....	3·9	·29
Rio Grande at Del Norte, Colorado	Dec., 1890	5, 930	307	1, 242	899, 208	1, 400	12·0	·89
	Dec., 1891	5, 650	290	1, 403	1, 015, 772	....	13·6	1·00
	Dec., 1892	4, 710	290	812	589, 480	....	6·9	·58
Rio Grande at Embudo, New Mexico	Dec., 1889	5, 660	181	1, 032	747, 168	7, 000	2·0	·15
	Dec., 1890	6, 071	260	1, 467	1, 062, 048	....	2·8	·21
	Dec., 1891	8, 550	225	1, 855	1, 343, 020	....	3·5	·26
	Dec., 1892	6, 665	140	1, 240	900, 190	....	2·4	·18
Rio Grande at El Paso, Texas	Dec., 1890	7, 200	40	1, 327	960, 748	30, 000	·60	·044
	Dec., 1891	16, 620	0	2, 653	1, 920, 772	....	1·2	·088
	Dec., 1892	10, 050	0	1, 285	933, 159	....	·6	·043
Gila	Aug., 1890	6, 330	11	503	364, 172	13, 750	·50	·037
Salt	Dec., 1889	33, 794	319	2, 576	1, 865, 024	12, 260	2·8	·21
	Dec., 1890	143, 288	397	3, 771	2, 730, 204	....	4·2	·31
Truckee, Vista	Mar., 1891	7, 510	400	1, 895	1, 371, 980	1, 519	17·0	1·25
	Dec., 1891	3, 285	370	980	709, 520	....	8·8	·65
East Carson	Mar., 1891	4, 260	375	970	702, 280	414	31·8	2·35
	Dec., 1891	1, 884	375	619	448, 156	....	20·4	1·50
	Dec., 1892	2, 590	290	610	442, 836	....	20·1	1·47
West Carson	Mar., 1891	1, 284	42	206	149, 144	70	40·0	2·94
	Dec., 1891	740	34	128	92, 672	....	24·8	1·83
Bear at Battle Creek	Dec., 1890	5, 980	270	1, 751	1, 267, 724	4, 500	5·3	·39
	Dec., 1891	3, 030	690	1, 224	886. 176	....	3·7	·27
	Dec., 1892	5, 260	600	1, 537	1, 115, 801	....	4·6	·34
Bear at Collinston	Dec., 1890	8, 220	1, 000	2, 945	2, 132, 180	6, 000	6·6	·49
	Dec., 1891	5, 000	825	1, 847	1, 337, 228	....	4·2	·31
	Dec., 1892	6, 260	1, 000	2, 097	1, 522, 333	....	4·8	·35
Ogden	Dec., 1890	2, 178	215	663	480, 012	360	25·0	1·84
Weber	Dec., 1890	5, 465	200	1, 070	774, 680	1, 600	9·1	·67
	Dec., 1891	4, 655	240	880	637, 120	....	7·5	·55
	Dec., 1892	5, 755	100	907	658, 446	....	7·7	·57
American Fork	July, 1890	885	6	146	105, 704	66	30·0	2·22
Provo	Dec., 1890	2, 260	200	572	414, 128	640	12·1	·89
	Dec., 1891	1, 704	200	503	364, 172	....	10·7	·79
	Dec., 1892	1, 780	200	469	340, 475	....	9·0	·73
Spanish Fork	Dec., 1890	1, 040	50	172	124, 528	670	3·5	·26
Sevier	Dec., 1890	2, 329	150	625	452, 500	5, 595	1·5	·11
	Dec., 1891	1, 386	140	535	387, 340	....	1·3	·10
	Dec., 1892	1, 222	48	401	291, 110	....	1·0	·07
Henry	Dec., 1890	7, 710	1, 120	1, 719	1, 244, 566	931	25·0	1·84
Falls	Mar., 1891	4, 440	450	1, 194	864, 456	594	27·2	2·01
	Dec., 1891	2, 790	450	773	559, 652	....	17·6	1·30
Teton	Mar., 1891	4, 445	400	1, 021	739, 204	967	14·4	1·06
	Dec., 1891	2, 360	400	696	503, 904	....	9·8	·72
	Dec., 1892	5, 270	450	1, 084	786, 941	....	15·3	1·12
Snake	Dec., 1890	50, 450	2, 000	10, 635	7, 699, 740	10, 100	14·2	1·05
	Dec., 1892	54, 300	2, 250	10, 025	7, 277, 749	....	13·5	1·00
Owyhee	Mar., 1891	11, 230	170	1, 656	1, 198, 944	9, 875	2·3	·17
	Dec., 1891	10, 000	200	1, 332	964, 368	....	1·9	·14
	Dec., 1892	18, 000	320	3, 268	2, 372, 446	....	4·5	·33
Malheur	Feb., 1891	4, 445	15	698	505, 352	9, 900	·96	·07
	Sept., 1891	2, 820	15	187	135, 368	....	·26	·02
Weiser	Feb., 1891	11, 220	80	1, 652	1, 196, 048	1, 670	13·4	·99
	June, 1891	9, 300	80	771	558, 202	....	6·3	·46

DEPARTMENT OF THE INTERIOR.—U. S. GEOLOGICAL SURVEY.

AMERICAN IRRIGATION ENGINEERING.

BY

HERBERT M. WILSON, C. E.

CONTENTS.

Page.
Preface 109
Introduction 113

CHAPTER I.

Economical and financial aspects of irrigation 121
Alkali and drainage 127
Silt and sedimentation 130

CHAPTER II.

History and legislation 133
Legislation and administration 139

CHAPTER III.

Hydrography, evaporation, and seepage 152
Duty of water 155
Alignment, cross-section, and slope 158

CHAPTER IV.

Classes of works 162
Perennial canals 163
Kings river canals 164
Calloway canal 168
Del Norte canal 171
Arizona canal 175
Highline canal 179
Wyoming Development Company's canal 181
Kraft Irrigation district canal 184
Pecos valley canals 187
Central Irrigation district canal 191
Bear river canal 194
Idaho Mining and Irrigation Company's canal 198
Turlock canal 203
Folsom canals 210
Other important canals 214

CHAPTER V.

Headworks 218
Weirs 219
    Crib 221
    Open 227
    Composite 230
    Masonry 230

Page.
Diversion dams 234
Regulators 238
Escapes 244
Falls and rapids 249
Drainage works, flumes, siphons, etc 256

Chapter VI.

Distribution and measurement of water 268
Application of water 274
Maintenance and supervision 281

Chapter VII.

Water storage 284
San Diego Flume Company 286
Merced reservoir 290
Long valley reservoir 294
Walnut Grove reservoir 297
Castlewood reservoir 302
Bear valley reservoir 305
Sweetwater reservoir 310
Other reservoir projects 314
Construction of dams 321

Chapter VIII.

Subsurface sources of supply 326
Pumping 332
Subirrigation 338
Tools and machinery 342
Authors' list 346

ILLUSTRATIONS.

Page.
Pl. CXI. Pueblo canal. Verde valley, Arizona ... 132
CXII. Del Norte canal. View of rapid ... 172
CXIII. Arizona canal system, A, and plan of headworks, B ... 174
CXIV. Arizona canal. View of Big fall ... 176
CXV. Pecos canal ... 190
CXVI. Bear river canal in canyon ... 196
CXVII. View of Idaho canal during construction ... 198
CXVIII. Phyllis canal pipeline ... 200
CXIX. Phyllis canal rapid ... 202
CXX. Turlock canal. View of main line ... 208
CXXI. View of pile weir across Platte river ... 220
CXXII. Arizona canal. View of second weir ... 222
CXXIII. Bear river canal. View of weir during construction ... 226
CXXIV. Calloway canal. View of weir and canal regulator head ... 228
CXXV. San Diego flume. View of weir ... 230
CXXVI. Folsom canal. Plan, cross section, and elevation of weir and headworks ... 232
CXXVII. Pecos canal. View of dam ... 234
CXXVIII. Del Norte canal. View of regulator from inside ... 236
CXXIX. Arizona canal. View of regulator gates ... 238
CXXX. Bear river canal. Elevation and cross sections of weir and regulator ... 240
CXXXI. Central Irrigation district canal. Plan and elevation of regulator ... 242
CXXXII. Folsom canal. View of weir and regulator ... 244
CXXXIII. Folsom canal. Plan, cross section and elevation of regulator ... 246
CXXXIV. Arizona canal. View of fall ... 250
CXXXV. Highline canal. View of bench flume ... 258
CXXXVI. San Diego flume. View on bench ... 260
CXXXVII. San Diego flume. Trestle across Los Coches creek ... 262
CXXXVIII. Pecos canal. View of flume ... 264
CXXXIX. Orchard irrigation by sidewise soakage from ditches ... 278
CXL. San Diego flume. View of tunnel and approach ... 286
CXLI. View of Castlewood dam ... 302
CXLII. Sweetwater dam. Plan, cross section, and details of wasteway ... 310
CXLIII. View of Sweetwater dam ... 312
CXLIV. San Mateo dam. Plan, cross section, and outlet sluices ... 320
CXLV. View of San Mateo dam ... 322
CXLVI. San Francisco Bridge Company's excavator ... 344
Fig. 64. Profile of Pueblo canal, Verde valley, Arizona ... 134
65. Ancient dam, San Luis Obispo county, California ... 136
66. Cross sections of canal banks, Calloway (A), Idaho (B) and Turlock canals (C) ... 160
67. Calloway canal system, A, and plan of headworks, B ... 170
68. Del Norte canal system, A, and plan of headworks, B ... 173
69. Del Norte canal. Plan of main bifurcation ... 174

Page.
FIG. 70. Wyoming Development Company's canal system, A, and cross section of weir, B 182
71. Kraft Irrigation District canal system 184
72. Kraft Irrigation District. Plan of headworks 185
73. Kraft Irrigation District. Excavation for fall 187
74. Pecos canal system 189
75. Bear river canal system 195
76. Bear river canal. Cross section of hillside work 197
77. Bear river canal. Cross sections of Corinne branch canal 198
78. Idaho canal system, A, and plan of headworks, B 199
79. Turlock canal system 204
80. Turlock canal. Plan of headworks 205
81. Turlock canal. View of sidehill work 206
82. Turlock canal. Cross section of sidehill work 207
83. Turlock canal tunnel 208
84. Folsom canal system 211
85. Arizona canal. Cross section of first weir 221
86. Arizona canal. Cross section of second weir 222
87. Highline canal. View of weir 225
88. Kraft Irrigation District canal. Cross section of weir 226
89. Calloway canal. Cross section of weir 228
90. Monte Vista canal weir 229
91. San Diego flume. Plan, elevation, and cross section of weir 230
92. Turlock canal. Cross section of weir 232
93. Folsom canal weir. Hydraulic jack 234
94. Idaho canal. Cross section of dam 235
95. Idaho canal. Plan and elevation of headworks 236
96. Pecos canal. Plan of headworks 237
97. Pecos canal. Cross section of dam 238
98. Del Norte canal. Elevation and cross section of regulator gates 240
99. Idaho canal. View of rolling regulator gate 244
100. Arizona canal. View of escape 246
101. Idaho canal. Elevation and cross section of escape 248
102. Folsom canal. Cross section and elevation of sand-gates 249
103. Calloway canal. View of fall 251
104. Arizona canal cross-cut. Cross sections of fall 252
105. Fresno canal. Plan and cross sections of falls 253
106. Bear river canal. Plan and cross section of fall on Corinne branch .. 254
107. Turlock canal. Cross section of fall 254
108. Uncompahgre canal. Cross sections of falls 255
109. Grand river canal. Plan and elevation of Big Drop 255
110. Turlock canal. Plan and cross section of Dry creek drainage dam .. 258
111. Types of flumes and trestles 259
112. Idaho canal. Cross section of low flume 260
113. San Diego flume. Cross section 261
114. Bear river canal. View of iron flume over Malade river 262
115. Bear river canal. Elevation and cross section of iron flume on Corinne branch 263
116. Arapaho canal. Cross section of siphon head 264
117. Del Norte canal. Cross section and end elevation of culvert 265
118. Central Irrigation District canal. Elevation and cross section of Stony creek culvert 267
119. Water distribution, Riverside, California 269
120. Laybourn iron flume. Perspective and cross sections 270

Page.
Fig. 121. Calloway canal. View of distributary head 271
122. Foote's measuring flume,A. Plan of water divisor, B 273
123. Irrigation by flooding 275
124. Application of water by flooding 276
125. Application of water by check system 277
126. Application of water by block system 278
127. Application of water by furrows 279
128. Merced reservoir system 291
129. Honey lake valley reservoir system 294
130. Honey lake dam, cross section 296
131. View of Walnut grove dam 298
132. Walnut grove dam. Cross section and elevation 299
133. Castlewood dam. Plan, elevation, and cross section 303
134. Bear valley reservoir system 305
135. Old Bear valley dam. Cross section 307
136. Old Bear valley dam. Plan and elevation 307
137. New Bear valley dam. Plan and cross section 308
138. Buchanan reservoir system 314
139. Citizens' Water Company dam. Cross section 318
140. Citizens' Water Company dam. Elevation 319
141. Bowman dam. Plan and cross section 323
142. Fordyce dam. Plan and cross section 324
143. San Fernando dam 332
144. Water wheel 334
145. Discharge flume from steam pump, Tucson, Arizona 337
146. Colorado wooden pipe 339
147. Alessandro hydrant 341
148. Buck scraper 343
149. Fresno scraper 344
149*a*. New Era excavator 345

PREFACE.

In this report I have made no attempt to describe all of the irrigation works of the arid West; such a task would be impossible of accomplishment, since new works are being constructed daily. Many of the irrigation works of the West which are important because of the large acreage they serve are so crudely constructed as to afford no features of interest for description. Many others are so small and the works upon them of such little importance as to render their description unnecessary.

I have endeavored to select such works for description as embody all the principal features distinguishing American irrigation engineering. There have been at least four different stages in the development of irrigation in this country. In the first, which is rather traditional than historical, were built the ancient canals and small storage works of the Aztecs or aboriginal inhabitants of the Southwest and the works of the earlier Mexican settlers, constructed two or three or more centuries ago. In the second were the works constructed over forty years ago by the earlier Mormon settlers in Utah, the American settlers in the neighborhood of the Mexican towns, and those who had gone to the West to follow the pursuit of mining and who discovered the necessity of cultivating crops for their own use and for sale. While not constructed according to any of the scientific principles laid down by engineers, these works were yet an advance on their predecessors. The third stage in development was entered upon about fifteen years ago, when engineers and surveyors, frequently skillful and well equipped in other branches of their profession, but ignorant of its application to irrigation, were called upon to construct works of larger magnitude and greater importance in the valleys of California and Colorado. These works furnish the true beginnings of American irrigation engineering, and some of the best of our constructing engineers of to-day are the men who built these earlier works, faulty though they are. The last and present stage in this development has been reached within the past two or three years, and has been brought about chiefly by the interest taken in irrigation by the Federal Government in the establishment of an irrigation survey under your charge, and by the appointment of State engineers in California, Colorado, and Wyoming, whose duties have been practically confined to irrigation.

As a result of the crowding of the East and an appreciation of the value of lands when irrigated, capital has been more readily forthcoming for the building of works. As a result of the massing of large amounts of capital in the hands of a few intelligent corporations organized for the purpose of constructing irrigation works, their officers have been enabled to employ skilled engineering advice. There are under construction to-day, or already completed, a number of great irrigation systems in the West which, while costing much less than those of equal magnitude in Europe or in India, are the equals of these in the quality and excellence of their workmanship and design. These works embody all of the peculiar characteristics which distinguish American works from those of Europeans.

The information contained in this report is peculiarly of an engineering character. No attempt is made to discuss the broad questions of legislation or the advisability of Government, State, or private control of canals. Until within the last few years the literature of irrigation in the United States was extremely meager, everything relating to the subject being contained in a few pamphlets descriptive of particular works and chiefly written for advertising purposes and to promote immigration to the lands commanded by those works. Within the last few years, however, there has been created an extensive literature, touching unfortunately on the general legislative and economic side of irrigation only. This is embodied in reports of the State engineers of California, Colorado, and Wyoming, in the reports of the Special Senate Committee on Irrigation, in the reports of the Agricultural Department and of the Geological Survey. These reports show chiefly what has been done in a general way in other countries and illustrate the value and necessity of irrigation, and discuss its financial outlook and the legislation necessary for its advancement. Nothing worthy of note has as yet been written descriptive of the engineering features of our works. It is to fill this want that this report has been prepared.

In consequence of its character it has been impossible to prepare such a report as this by means of compilation. The bulk of the material contained in it has been obtained by actual inspection of the works described, and is the result of about five years of labor, not only in designing works for the irrigation survey but in examining and making notes of the majority of the irrigation works constructed by private parties, usually with the aid of engineers and owners of these works. Much general information and some detailed descriptions have been culled from various pamphlets to which reference is made in the footnotes.

I desire here to acknowledge generally the universal courtesy with which I was treated and to return my thanks to the engineers and officers of the various companies for the facilities granted me. While I have endeavored as far as possible to give the names of the engineers connected with the various works in the body of the report, I have avoided criticising these works either favorably or otherwise, preferring to permit readers to form their own conclusions. In most cases where faulty work has been constructed the engineers should not be blamed for ignorance or incapacity; they have frequently been compelled from financial and economic reasons, the result of the construction of these works by private capital, to do work of which their scientific judgment did not approve.

Whatever of a general or descriptive nature occurs in this report has been written with a view to collating and simplifying the pamphlets recently published on this subject. This would not be necessary but for the fact that it will reach many to whom these pamphlets are generally inaccessible, and especially engineers in foreign countries who are unacquainted with the general principles guiding the development and construction of American works.

H. M. W.

AMERICAN IRRIGATION ENGINEERING.

By Herbert M. Wilson.

INTRODUCTION.

As a result of the extremely dry season of 1889 various methods have been suggested to save investments already made and still further to extend the cultivable area in the arid regions, though that year has been succeeded by two successive seasons of abundant rainfall. Various suggestions for the increase of the water supply have been discussed and much has been done for the successful accomplishment of this object.

The chief sources of water supply are (1) rainfall; (2) running streams or springs; (3) storage reservoirs; (4) ground water supplies; (5) artesian wells. It is now generally agreed by those who have watched recent experiments to produce rainfall artificially that these will not result in any benefit to the arid regions. Irrigation from water sources inherent in the soil and more obedient to the leadership and control of man than is the atmosphere must be relied upon for the cultivation of crops. Much money and thought have been expended during the past two years in the development of the subsurface and artesian water supplies. These can scarcely be said to have resulted as satisfactorily as their projectors had hoped. Much useful information bearing upon the extent and distribution of the various artesian belts has been written, and numerous wells have been sunk as a consequence, but the discharge and value of these is relatively insignificant. It is doubtful if a hundred thousand acres over and above the area already irrigated by artesian wells will be supplied from this source for many years to come. The average well is capable of irrigating but a comparatively small acreage, and until water becomes more scarce than it is at present their chief value will be for domestic purposes and for watering cattle.

Much has been written recently regarding the so-called "underflow," by which is meant the seepage or ground water, which is at a short depth beneath the surface, and which is tapped by the common well. It is claimed that the volume of this underflow water, especially on the great plains, sloping eastward from the Rocky Mountains, is such as to render irrigable in the near future vast tracts of that region. But it has been discovered by experiment and investigation that the discharge from such sources is exceedingly limited. Tunnels or trenches of sufficient depth may be sunk into the ground and run along it for great distances to intercept this water of percolation, though the volume obtained by them is very limited and their multiplication is impossible, as each work of this kind materially affects the output of any similar work which may lie below it. The methods of utilizing ground waters are: (1) by open ditches; (2) by water raised to slight elevations by mechanical means; and (3) by water raised from the ordinary farm wells.

Pumping by means of windmills or steam will ultimately be largely resorted to, and areas irrigated by this means will be enormously increased as the country becomes more settled. Few pumping plants have as yet been established in this country for irrigating purposes, but such as have been have generally proven successtul and have shown that this method of procuring water is cheaper than is generally supposed. There are numerous isolated cases in which ground water is a matter of considerable moment and importance. This is especially true in the dry beds of some of the streams of Southern California and Colorado. In the former State tunnels have been run under the beds of the streams in a few cases, and in a few others dams resting on impervious foundations have been built across the channels of the streams, thus raising the subsurface water, and producing a sort of subterranean reservoir which furnishes an abundant supply of water for purposes of irrigation. Similar works are now being constructed in a few of the gulches on the eastern slopes of the Rocky Mountains, the most notable of which is for the water supply of the city of Denver.

The people of the West have found it necessary to turn their attention, for the irrigation of the vast bulk of the arid lands, to other sources of supply than the small streams, which are now almost all utilized. These were cheaply dammed and diverted by the simple means at the command of farmers, and until their waters had been utilized there was little room for the development of larger irrigation projects. Recently it has been necessary to devise means for the utilization of the larger streams, and now many projects are under investigation or construction which attack nearly all of the streams of greater magnitude. As yet, however, water has not become so scarce that it has been necessary to attempt to divert the waters of such great rivers as the Columbia, Sacramento, Colorado, and Rio Grande. This time must soon arrive, however, and when it does, the engineering problems which their utilization will raise will far surpass in magnitude anything of the kind yet undertaken in America.

Much of the water which is collected in the smaller streams in the mountains is lost by seepage and evaporation shortly after it reaches the plains, while the greater proportion of the water flowing throughout the year is lost during the long period from August to April, when irrigation is not practiced. It is during this season, moreover, that the streams carry the greatest flood volumes. This water must soon be saved by means of storage reservoirs, for utilization during the irrigating season. Such works will add enormously to the volume of water available for irrigation.

The first direction taken by public thought on the necessity of increasing the water supply was the construction of such supplementary works as storage reservoirs, the boring of artesian wells, and the development of the subsurface water, as shown above. But this is not the only resource. Much can be done in extending the benefits of even a limited water supply. The economic use of water first, and after that the application of higher and more scientific methods of cultivation, will greatly extend the area cultivable from the present available sources. As will be shown later on, the duty of water—that is, the area which a given volume of water will irrigate—is being constantly increased, as the proper method of handling water becomes better understood, and as the dry earth becomes saturated through successive seasons of irrigation. The cultivation of the soil, breaking it up by means of plows and its enrichment by the decaying vegetable matter will also aid largely in increasing the duty of water. By these means alone the value of the present available sources may in time become nearly doubled and the areas irrigable from these sources be correspondingly increased.

The development of the scientific practice of irrigation engineering in this country is a thing of to-day. Until about 1882 there can scarcely be said to have been constructed a single irrigation work designed on sound engineering principles. The art of American irrigation engineering has only been developed within the past few years, while the majority of the more modern and creditable works are but now approaching completion.

The early works of Colorado and California were all hastily constructed under great pressure from their owners, in order to realize some money return at the earliest possible moment, and as a consequence the charges for maintenance and repairs have been so great that the financial results have been far below the expectations of their projectors. Experienced engineers were not employed on many of these works; county surveyors, or, in fact, anyone who could run a level and discover section lines, were employed to stake out the lines, while contractors or farmers designed the dams, regulators, and other works. The grades, velocities, and capacities of the canals were matters of chance or guess rather than computation. It was not until within the last decade, when such works as the High Line and Del Norte canals of Colorado, the Arizona canal of Arizona, and the Calloway canal of California, were constructed, that experienced engineers were employed to design such works. In fact, it would be an error to say that the men who built those works were experienced irrigation engineers, for, while most of them had much experience in other branches of civil engineering, irrigation practice was then an entirely new departure to them, and only now is the science of irrigation engineering becoming properly understood. In the earlier works little attention was paid to the hydraulics of engineering, and the dimensions of the canals were more likely to be limited by their cost than by the volume of water available for diversion from the stream.

Like everything which Americans undertake, now that they have really begun to be interested in irrigation development, they are bringing to bear upon it their proverbial push and energy, and the advance made in the number and magnitude of the works is only keeping pace with the skill and intelligence displayed by engineers in overcoming difficulties and in appreciating the science of irrigation engineering. The changes wrought in the practice of this science in the past few years are astounding. There are to-day under construction numerous irrigation works, both for the utilization of the perennial flow of the streams by direct diversion and for saving the storm flow of intermittent streams by means of storage. Of these a dozen canals are completed or under construction which have capacities varying from 1,000 to 2,000 second-feet with bed widths of from 50 to 70 feet, the length of the main lines of which are from 50 to 100 miles, with as many more miles of laterals and distributaries. Such canals will irrigate from 100,000 to 150,000 acres each, and will render habitable twice that area, affording at an average of 40 acres to a farm, homes and support for 3,000 families each. Of storage reservoirs, there are a half dozen completed or under construction, which will impound from 800 to 300,000 acre-feet of water each, or sufficient to irrigate and reclaim more than half that many acres of land.

While not of such magnitude as those of India, the irrigation works of the United States are second in importance to those of no other country in the world, and, in many respects, compare very favorably with the Indian works. The area of land commanded by works either completed or under construction is second only to that in India. Except the Cavour canal, in Piedmont, Italy, there is no work of this kind in Europe which compares in size with our more modern canals. There are four essential points of difference between the irrigation works of this country and those of India. The first relates to the ownership and legislation; the second, to engineering; the third, to construction; and the last, to superintendence and maintenance.

In India all land and all water belong to the government, and the irrigation works are designed, constructed, maintained, and operated by the government. In consequence of this the legal questions involved are comparatively simple. They relate chiefly to the amounts of water to be distributed to consumers and the right of way through improved land. The question of profit is not always paramount, and while the direct money return is often small, the indirect return to the government is always large, in enhanced revenues from the rental of land, in immunity from famine, and the consequent heavy drain on the treasury for relief and charity, and in the general benefit to the people resulting from increased resources and exports. In the United States, while the general government benefits, as does that of India, from the last cause, the owner of the irrigation works does not, as he is invariably a private individual or corporation. Then, as the lands are all private property, and the water the property of the public until appropriated, the constructors do not benefit by enhanced value of land unless they purchase and own it. The priority of right to appropriate water, and the ownership thereof give rise to some of the most troublesome and expensive legal complications with which the Western people have to deal. Direct money profit is essential to any irrigation project in this country, and in our most successful works this profit has been chiefly realized from the sale and ownership of land, the value of which has been increased by furnishing it with a water supply.

As to the second point of difference, that of engineering, the character of the Indian rivers and their relation to the irrigable lands is such that the canals taken from them rarely require long or difficult diversion lines to bring the water to the lands. The chief engineering difficulties encountered are in constructing stable diversion weirs and headworks in the sandy river beds, and in contending against the enormous flood discharges of those rivers. In most portions of our country good firm rock or heavy gravel and clay soils can be found, in which to locate headworks; while the relation of the streams to the irrigable lands is generally such that long and difficult diversion lines have to be constructed before the water becomes available. In other words, the chief skill of the Indian engineer is required in locating and constructing the headworks; that of the American engineer in building the first dozen miles or so of his canal line. The only Indian canal of magnitude having a difficult diversion line is the Ganges canal, a description of which was given by me in a previous report.[1]

The third point of difference, which is of a structural nature, is chiefly due to the haste demanded and the cheapness required in the first cost of constructing these works. In India the works are built by the Government, and accordingly designed with a view of making them so permanent that they will last almost forever, and that the charges for maintenance and repairs shall be a minimum. To this end all irrigation projects are carefully thought out and surveyed and resurveyed until the best possible location has been chosen and the details of the scheme perfectly elaborated. The weirs, headworks, aqueducts, and regulating gates are all constructed of the most substantial masonry, and the repairs to such works are reduced to a minimum. With us the main object is to reduce the first cost to the lowest possible figure, in order that the works may be completed quickly and cheaply and the investors begin to derive some profit at the earliest possible date. Our diversion weirs have, therefore, generally been constructed of cheap wooden framing, and occasionally, as an unusual extravagance, of rock-filled crib work, while many canals, especially in California, are taken directly from the streams by a simple inlet, with no dam or other diversion weir. Little time is spent in ascertaining the best location, either for the headworks or the canal line, and wood is universally employed in the construction of flumes or aqueducts, regulating gates, and falls.

---

[1] Twelfth Ann. Rept. U. S. Geol. Survey, pt. II: Irrigation in India, by H. M. Wilson, 1891.

The pressure which engineers are now bringing to bear upon the projectors of irrigation works is such that more good, substantial, and permanent work is being done than at any time in the past history of irrigation development in this country, and the date is not far distant when our irrigation works will be designed and constructed with the care they deserve. There is even less excuse for faulty and unsafe work on an irrigation system than on a railway; for should a railway bridge be badly constructed and give way, the lives of only those few persons who are upon the train which falls through it are lost, and if the line is badly located the chief loss to the company is in deterioration of the rolling stock and added cost of haulage; but if a dam or similar work on an irrigation system gives way, not only are the lives of those whom the floods may engulf endangered, but a large amount of property is destroyed, and the lack of water for the irrigation of the crops may impoverish and render destitute hundreds of families who are dependent upon the water supply to mature their crops. In addition, the bad location of the canal line and cheap construction of works frequently mean such enormous outlays for repairs and maintenance as consume all the returns from water rentals and run the company into debt.

The fourth point of difference referred to between Indian and American irrigation works is in the maintenance and supervision of these works. In India the completion of an irrigation system is no reason for dispensing with the services of the engineers. A chief engineer, with his assistants, who have charge of the various divisions of a canal, is always retained in order to keep the works up and to design and superintend improvements. In addition to the engineer corps are overseers and patrols, the latter having comparatively short sections of the canal, which they walk daily in order to report the condition of the works, make or suggest needed repairs, and especially to perform police duty by preventing damage being done by heedless or vicious persons, and to keep cattle from tramping over the ditches. The superintendence by these engineers and overseers renders it possible to keep the canal up to the highest state of efficiency, and the magisterial and police powers given them enable the canal officials to arrest and punish offenders against canal laws.

With us, after a canal system is completed, the services of the engineer are usually dispensed with, and the supervision and maintenance of the work falls to the lot of some superintendent who may be a farmer having no knowledge of engineering and as little of the needs of the work under his charge. Gophers are permitted to burrow at discretion in the canal banks, and small leaks go unattended to, as their dangers are unappreciated, while flumes and weirs and other perishable works are permitted to remain unrepaired until they are past repairing and must be renewed. Rarely is any proper system of patrol in operation; sometimes ditch riders are employed, though usually only on the more dangerous sections of the canal. On the vigilance and skill of the patrolmen and superintendent largely depends the successful operation of a canal system, and this branch of the service is that which is most neglected and least thought of in the administration of American canals.

Before entering upon a detailed description of American irrigation methods it is desirable to consider the history of the course of events which led up to their adoption. The mode of application of the water and the manner of constructing the works have rarely been the result of any prearranged plan, but have as a rule been brought to their completed state by a series of progressive evolutions. Not only are American works not state works, but in the beginning they were not constructed by companies or capitalists, but by the farmers themselves, singly or banded together. As a result of the old pioneer spirit, the settler took up land, and after he had planted his crop, seeing himself in danger of losing it by drought, he looked about for some means of providing water. With the pressure of immediate want upon him, he had no time to obtain engineering advice or to gather together a company of capitalists, but he had to take his plow and shovels and carts and throw up some temporary obstruction in the stream to divert the water and dig a rude ditch to his fields. As a result of this he obtained a much greater crop than his less thrifty neighbors, and stirred by the sense of successful efforts he improved on his work by making it more permanent. Later on he was joined by his neighbors, who, desiring to take advantage of his dam or a portion of his canal, banded with him, and from these beginnings community ditches and works were constructed. The results of these works became so apparent in a short time that owners of large tracts of land who desired to find a market for them, interested capitalists in projects for their irrigation, and these, seeking engineering advice as the best means of accomplishing the result, brought about gradually the present state of progress.

In the earlier works the rude dams which were at first constructed were frequently carried away by floods, and each was replaced by a more substantial affair, the form of construction of which was indicated by the weakness of its predecessor. As the rudely graded canals eroded or destroyed their banks, their owners began to appreciate the necessity of proper construction on these and modified them according to the dictates of their own judgment or as the result of proper engineering advice. Still, in some cases, the practice survives of putting up a weir that will stand for ordinary seasons, foreseeing that it will be swept away by the heavy floods, and as profits are gained and additional means are obtained these temporary devices are replaced by more substantial ones. Throughout all our works are seen ingenious devices for decreasing expenses, the result of a desire to save interest and diminish the chances of failure. Especially in the first construction of works no money is spent in making them more permanent or durable than is absolutely necessary. This mode of procedure is rarely a result of the judgment of the engineers. In this country the private capitalist takes advice of the engineer, but acts according to his own judgment and to his immediate interest. The engineer is not called upon to decide whether the soil is suitable or whether paying crops can be raised or what is the financial prospect. The capitalist or promoter considers these problems and asks the advice of the engineers as to the best manner in which to construct the works for the irrigation of the lands chosen. He then decides whether he can afford the expenditure suggested by the engineer, and usually compels the latter to modify his plans so as to enable the work to be constructed in the cheapest and quickest manner.

It seems strange that while in all their large engineering undertakings Americans are well to the front they are decidedly behind as irrigating engineers. The responsibility of designing and constructing a canal or reservoir system from beginning to end is often too lightly assumed. Especially is too little attention paid to the first reconnaissance, examinations, and locations. Above all other classes of work those for purposes of irrigation should be of the most permanent and solid character, and the greatest skill and forethought are necessary in properly proportioning and designing all the parts; so that when once constructed there should be no danger of an accident which will perhaps leave a heavily populated region without the water necessary to mature the crops.

CHAPTER I.

ECONOMICAL AND FINANCIAL ASPECTS OF IRRIGATION.

The semiaridity of the Great Plains region east of the Rocky Mountains has caused a loss of 20 per cent at least in its productions. If an assured water supply were at command in this region values would rise as by magic. Within the past few months experiments and attempts have been made in southern Texas to produce rain artificially. The anxiety of the people of that region to have an assured water supply is shown clearly by the great sums of money which they raised to pay the expenses of these experiments. Though they have practically proven failures so far and have given little promise of success, yet every town in Texas has held its mass meetings and has subscribed money for the furtherance of the work of cannonading the heavens, which has been conducted by Mr. Dyrenforth. During this period land values fluctuated with greatest rapidity. They went up 5 and 10 and 15 per cent; they fell with the reports of failure, and rose again with new accounts of success. In Kansas whole counties have banded together and in one case have offered 10 cents per acre for the entire area of their territory to these rainmakers if they will produce the desired downpour. No better instance of the appreciation of the value of water in the arid lands could be cited.

If the fruit crops of the arid States were entirely dependent upon rainfall as are the wheat crops of the plains, the enormous loss that would follow a drought can be easily appreciated. Peach, apricot, and prune orchards return profits of from $100 to $150 per acre. The raisin grape from $200 to $250, and oranges and olives from $300 to $500. The loss of 20 per cent. on such crops would reach a very large sum. A striking evidence of the change wrought by irrigation is exhibited by Fresno county, California, where, in 1871, a colony of 500 people laid out 5,000 acres in small vineyards. This colony is now, perhaps, with one or two exceptions, the most prosperous in California. The settlers that brought the 5,000 acres of land, paying $2.50 per acre, later on became the supporters of the Fresno Canal and Irrigating Company, which had a length of 40 miles of main line. In 1870 there were less than 5,000 people; in 1890 there were over 100,000. More than 20 colonies have since been located, and 20,000 acres of vineyards are directly tributary to the city of Fresno. In 1873 the raisin grapes began to bear, and 6,000 boxes were shipped; in 1890 over 1,000,000 boxes was the product. From $2.50 per acre the value of the unimproved land has increased till at the present time it is worth from $50 to $100 per acre, while improved land under ditch is worth from $100 to $300 per acre. In 1870, before the production of orange and raisin grapes in the neighborhood of Riverside, Cal., one of the largest landowners in that State pleaded to have his taxes reduced to 75 cents per acre. It took 800 acres to support a ranchman, and 25 to feed a single cow; now 6,000 people live there on 6,000 acres. Of this area 3,000 acres are in oranges, the oldest trees being but 15 years old. In 1890 there were shipped to market 480 carloads of lemons and oranges, at an average value of $800 an acre, or a total of $1,184,000—a net return of $395 per acre.

Irrigation will, in the near future be so thoroughly appreciated that it will be practiced in large portions of what is now considered the humid region. In Italy, France, and most of India the rainfall is ample for ordinary crops. Nevertheless, irrigation is practiced to increase the yield and offset the consequences of drought. The general impression that irrigation is necessary or useful only in dry countries is entirely erroneous. It is such regions as the semiarid plains of Kansas, Nebraska, Oklahoma, Dakota, and eastern Texas, which are especially in need of irrigation. In the whole arid region there would be no settlement other than that which could be supported by the few springs and living streams were it not for irrigation; consequently there would occur none of the great losses from drought and famines which are periodical in the semihumid portions of the West, for, as the rainfall is insufficient to raise crops in the arid regions, no one thinks of planting them with the hope that they will be watered by nature.

In the semihumid regions on the contrary there occur cycles of wet seasons when the rainfall is sufficient to produce abundant crops. People flock to these regions, build houses and barns, erect fences, and spend their all, as well as mortgage the property with the hope of gaining homes and a livelihood for themselves. Then comes a period of drought. Two or three successive years with half crops render the inhabitants destitute; they lack the means to purchase food, and were it not for our magnificent transportation facilities, and the charity of the people, such famines as have devastated India might occur. The poor settlers move to some more hospitable region to start anew, only to be followed during the next succession of wet years by others who will experience the same difficulties. It is such a region as this, above all others, which needs the protection of irrigation. The water may be required only once in a few years, but when wanted if not forthcoming its lack means the loss of many homes, and the destitution of thousands of families. That this is no exaggeration is testified to by the reports published in our Eastern papers. In August, 1890, the papers of the country published dispatches from Oklahoma announcing that the settlers were in the direst distress or actually starving. It was stated that the country was not producing enough to keep the people from starvation, and that the settlers had been there for nearly two years without being able to raise enough to live on. This was a result of the two dry seasons of 1889 and 1890 following each other, and a similar effect was produced in other portions of the semihumid region.

The cost of irrigation by means of any great canal or storage system varies over a wide range. Where the water can be easily diverted by means of some simple headwork or obstruction in the stream, and where canal construction is through easy earth excavation, requiring no expensive works, the cost per acre may be relatively very small. As the expense of diversion increases and the expense of building the canal increases, so the cost per acre of supplying water increases, and the addition of storage works entails an additional cost per acre for supplying water. All of these expenses must be compared with the probable returns both from the sale of perpetual water rights or of land with water rights attached to it and the returns realized on annual water rentals. In portions of Montana and Wyoming the products of the soil have relatively so low a market value that the land will at present scarcely bear an annual charge exceeding $2 per acre for water, and land with a water right in perpetuity will scarcely pay interest if its cost exceeds $25 per acre. These relative values are increased in Colorado, Idaho, and Utah to more than double this amount, while in southern Arizona and California there is scarcely any limit yet placed on the price which may be paid to bring water to the best agricultural lands. Land, which with a permanent water right attached to it costs $1,000 per acre, readily yields in some places in California 8 and 10 per cent interest, while water rentals as high as $10 and $20 per acre have in some cases been paid and the farms have still been worked to a profit. In such cases enormous outlays may be incurred for the supplying of water.

The following table shows the cost of some storage works in India and in different parts of this country:

Cost of water storage.

Reservoir.	Locality.	Material of dam.	Cost per acre-foot stored.
Sweetwater (constructed)	California	Masonry	$40.90
Bear valley (constructed)	do	do	5.30
Merced (constructed)	do	Earth	26.60
Cuyamaca (constructed)	do	do	9.00
Boman (constructed)	do	Crib and loose rock.	11.18
Eureka lake (constructed)	do	do	2.50
Long valley (estimated)	do	Earth	2.21
Hemet valley (estimated)	do	Masonry	9.98
Tuolomne meadows (estimated)	do	Loose rock	3.66
Little Yosemise (estimated)	do		13.65
Lake Eleanor (estimated)	do		2.10
Upper Sun river (estimated)	Montana	Masonry	5.06
Lower Sun river (estimated)	do	do	10.06
Willow creek (estimated)	do	Earth	4.55
El Paso (estimated)	Texas	Masonry	5.00
Castlewood	Colorado	do	38.00
Twin lakes (estimated)	do	Earth	2.00
Swan valley (estimated)	Idaho	Loose rock	.33
Jackson lake (estimated)	Nevada	do	.20
Webber lake (estimated)	do	do	3.90
Middle Carson (estimated)	do		4.88
Periar (constructed)	India	Masonry	4.65
Bhatgur (constructed)	do	do	3.20
Betwa (constructed)	do	do	8.90
Ashti (constructed)	do	Earth	4.80
Ekruk (constructed)	do	do	4.00

The above figures have in some instances been greatly increased by the charges for right of way. In the case of the El Paso reservoir, notably, the estimated cost per acre-foot was more than doubled by the necessity of purchasing land and removing railways.

The following table is copied from the valuable Census bulletins prepared by Mr. F. H. Newell, of this Survey. As far as the results can be obtained by inquiry they give accurately statistical facts of importance bearing upon the extent, cost, and value of irrigation in the United States:

Extent and cost of irrigation

States and Territories employing irrigation.	Crop irrigated.	Per cent of area of irrigated crops to total land area.	Total number of farms with irrigated crops.	Per cent of area of irrigated crops to whole area owned by irrigators.	Average size of irrigated crops per farm.	Average first cost of water per acre.	Average value of water per acre as estimated by irrigators.	Average annual cost of water per acre.	Average cost of preparing land for cultivation per acre.	Average value of land irrigated per acre.	Average value of products from irrigated land per acre.
	Acres.				*Acres.*						
Total U. S.	3,564,416	0·50	52, 584	20·72	67	$8. 15	$26. 00	$0. 99	$12. 12	$83. 28	$14. 89
Arizona	65, 821	0·09	1, 075	43·21	61	7. 07	12. 58	1. 55	8. 60	48. 68	13. 92
California	....	1·01	13, 732	17·86	73	15. 84	52. 28	1. 60	22. 27	150. 00	19. 00
Colorado	....	1·34	9, 659	31·09	92	7. 15	28. 46	. 79	9. 72	67. 02	13, 12
Idaho	218, 249	0·40	4, 333	26·08	53	4. 74	13. 18	. 80	9. 31	46. 50	12. 93
Montana	350, 582	0·38	3, 706	23·05	95	4. 63	15. 04	. 95	8. 29	49. 50	12. 96
Nevada	224, 403	0·32	1, 167	14·13	192	7. 58	24. 60	. 84	10. 57	41. 00	12. 92
New Mexico	91, 745	0·11	3, 085	17·98	30	5. 58	18. 30	1. 54	11. 71	50. 98	12. 80
Oregon	177, 944	0·29	3, 150	15·89	56	4. 64	15. 48	. 94	12. 59	57. 00	13. 90
Utah	263, 473	0·50	9, 724	22·02	27	10. 55	26. 84	. 91	14. 85	84. 25	18. 03
Washington	49, 399	0·12	1, 050	17·21	47	4. 03	13. 15	. 75	10. 27	50. 00	17. 09
Wyoming	229, 676	0·37	1, 917	15·24	119	3. 62	8. 69	. 44	8. 23	31. 40	8. 25
Total for eastern sub-humid region	67, 295	0·02	1, 557	6·43	43	4. 07	14. 81	1. 21	4. 62	......	......
North Dakota	445	0·001	7	34·76	63	......	......	. 25	6. 42	......	......
South Dakota	15, 717	0·03	189	29·95	83	3. 20	17. 90	. 66	7. 81	......	......
Nebraska	11, 744	0·02	214	14·44	55	4. 42	7. 59	. 48	4. 86	......	......
Kansas	20, 818	0·04	519	12·92	40	4. 00	21. 12	1. 45	3. 05	......	......
Texas	18, 571	0·01	628	2·47	30	6. 14	23. 57	1. 10	11. 60	......	......

Many valuable conclusions may be drawn from a careful study of the above table. As will be seen, the total area of crop irrigated is 3,564,416 acres. Of this amount at least a million acres consist of natural or wild meadow lands, which are flooded with water from some source and are cut for hay. This land has not been cultivated nor sown with seed, and is therefore not entitled to a place with irrigated crops. The low first cost of water in such states as Wyoming and Montana, as compared with Utah, Nevada, Arizona, and California, is a result of the fact that in the former states are innumerable small streams which have been easily diverted by the farmers, while little preparation has been necessary for the cultivation of the crops. In the latter states the water supply is scarce and valuable, and extensive engineering works have had to be constructed for its utilization, while the land has been carefully prepared for the application of water in order that it might perform the highest possible duty.

Mr. Newell roughly estimates that, in Wyoming, of the total area irrigated about 90 per cent is untilled. In Montana about 50 per cent is untilled, and this proportion diminishes until in California and Utah perhaps only 2 to 3 per cent of the entire area irrigated is untilled. This fact is shown throughout the table, as it brings down the average in the states in which the greatest area is untilled, both the average of the first cost of water and value of water per acre and the values of the products.

According to Prof. L. G. Carpenter[1] the total amount spent on irrigation works constructed in Colorado prior to end of 1889 was $15,000,000. In water division No. 1 there were 2,839 miles of canals, which cost $4,400,000—an average of a little under $2,000 per mile. These canals irrigated about 782,000 acres, showing an average cost of about $6 per acre irrigated. The proportionate cost in other divisions in the State of Colorado was similar, the grand total for the State being 6,317 miles of canals, which cost $10,980,000 and irrigated 1,635,000 acres. This is equivalent to an average cost of about $1,700 per linear mile of canal constructed, and about $6.75 per acre irrigated.

The following figures are taken from the reports by Mr. William Ham. Hall,[2] consulting engineer to the state irrigation districts of California, made in 1891. In this report the cost of irrigating the central irrigation district was calculated by dividing the total cost in money by the gross acreage directly capable of being served, and gave as a result $6.03 as the cost per acre. Owing, however, to the difficulties of issuing bonds and the consequent heavy interest account, the cost of irrigation in this district was brought up to about $12.50 per acre. In his report on the Perris irrigation district[3] Mr. Hall found that the total cost of the enterprise per acre of the entire district would be about $31.10. Deducting the cost for the intermediate distributaries, the cost for main line and branches will be $26.21 per acre. These high figures are the result of two causes—first, the water for the irrigation of this district is obtained by purchase from a water storage company; and secondly, these figures include the cost of laying a system of underground distributing pipes to every 10-acre plat in the district. These figures, however, are comparatively low when we recall that the lands in this district are worth from $600 to $1,000 per acre, and will return fair interest on that outlay.

The following table shows the cost of constructing some irrigation works in different parts of the world:

---

[1] Agricultural Experiment Station, Colorado State Agricultural College, third annual report, Fort Collins, Colorado, 1890.

[2] Central irrigation district, William Ham. Hall, San Francisco, California, 1891.

[3] Perris irrigation district, William Ham. Hall, San Francisco, California, 1891.

Cost of some irrigation works.

Name.	Locality.	Cost of works.		Value of water-right per acre.
		Per acre irrigated.	Per second-foot for water used.	
Carpenteras canal	France	$35.67	$2,830.19	
Verdon canal	do	81.25	15,330.19	
Henares canal	Spain	46.66	7,500.00	
Ganges canal	India	14.15	....	
Eastern Jumna canal	do	6.11	....	
Western Jumna canal	do	10.88	....	
San Diego Flume Co.	California	140.00	50,000.00	
Riverside Colony enterprise	do	100.00	5,000.00	
Gage canal	do	65.00	1,700.00	
Uncompaghre canal	Colorado	3.35	300.00	
Empire canal	do	1.00	120.00	
Citizens canal	do	1.25	125.00	
High-line canal	do	13.00	600.00	
Cottonwood reservoir	do	10.00	....	
Arizona canal	Arizona	10.00	700.00	12.00
Fresno canal	California	1.00	70.00	6.00
Calloway canal	do	10.00	710.00	
Merced reservoir	do	20.00	....	10.00
Kings River canal	do	7.18	277.00	
Turlock canal (estimated)	do	14.50	730.00	
Pecos canal	New Mexico	5.00	690.00	10.00
Pocatello canal (estimated)	Idaho	2.00	290.00	
Idaho Mining and Irrigation Co. (estimated)	do	2.16	190.00	
Bear River canal	Utah	5.00	125.00	10.00

About the heaviest expense incurred in western works is the charge made for the right of way and for the condemnation of reservoir sites. In the central irrigation district of California the right of way charges amounted to $59,039 for land and land damage and $10,576 for crop damage for 745 acres which were acquired, while for 124½ acres wanted the owners asked $25,432, or $212.21 per acre. Heavy charges for purchase of reservoir sites are sometimes incurred, as in the case of the El Paso reservoir, already cited, where the cost of construction was estimated at $304,000, while the purchase of land to be flooded would cost $69,000 and the removal of railways $590,000.

Owing to the methods of construction generally employed maintenance charges have been unusually high. Mr. A. J. Bowie estimates this to amount to $400 per mile in California for small canals, while Mr. G. G. Anderson states that in Colorado for moderate-sized canals $150 to $200 per mile is a fair estimate.

The returns from irrigation in most cases are so great as compared with the cost shown in the table, that this cost need in a very few cases be an impediment to the construction of works, providing a demand could be had for all of the water furnished. This, however, is the vital point in all western irrigation projects. In Montana and Colorado and similar states $8 to $12 per acre irrigated may be readily charged for a water right in perpetuity and $2 to $3 per annum per acre for water rentals. These figures would return a very fair interest on the average canal or reservoir provided all of the water supply were utilized. In California similar estimates may be made, but in that state the demand for water is so much greater than in other portions of the West that most of the well-constructed works can be relied upon to pay interest upon the investments.

In the central western states, however, it is not the feasibility of a project from a theoretically financial point of view that stands in the way of its construction; it is the lack of people to inhabit and cultivate the lands served by the project, for this forces a large proportion of the water furnished to remain uncalled for. If an irrigation project would pay 10 per cent interest, providing all of the water furnished were demanded and used, it would pay less than 2 per cent interest if there were a demand for but one-fifth of the water furnished. The great problem to be confronted by most irrigation projectors at present is immigration, not irrigation. If but a few good projects were started in the entire West, sufficient settlers could probably be found to make these interest-paying, but as there are many projects on foot, they divide up the number of settlers to such an extent that many must prove financial failures for many years to come and until valuable lands become more scarce and settlement more dense. In India, well inhabited as that country is, experience has proven that it takes from ten to twenty years after its construction for an irrigation work to reach its highest state of production, since it takes this time for people to come to an appreciation of the value of the water furnished and to demand all of it that is available.

ALKALI AND DRAINAGE.

The cause of the appearance of white flocculent salts on the surface of the ground in certain portions of the arid regions and the means of removing this salt from the soil have been matters of the greatest interest to irrigators and engineers ever since agricultural pursuits have been followed in the West. This white salt is commonly known as "alkali" and consists chiefly of various alkaline salts, among which the most prominent are chlorides, carbonates, and sulphates of sodium, potassium, calcium, and borax. The effect of this alkali on the soil is to render it barren and to prevent the cultivation of any crops wherever it appears on the surface.

Great areas originally existed which were covered with alkali; since the adoption of irrigation these areas have been occasionally extended or new alkali lands have been created, though in a few cases remedial measures have had the effect of reclaiming them. There is no doubt that irrigation, if practiced ignorantly and carelessly, may result in the production of a film of alkaline salts on the surface of the ground, though it is equally certain not only that the intelligent practice of irrigation need not be accompanied by these results, but that lands which were originally alkaline may be made arable. With an increased knowledge of the necessity of natural or artificial drainage as an adjunct to any well-planned irrigation project and a better understanding of the proper method of locating and constructing canals so as to produce a minimum rise of the subsurface water level, the production of alkali may be reduced to a minimum or wholly stopped.

One of the causes to which may be attributed the high degree of success attending irrigation in Los Angeles and San Bernardino counties in California, doubtless lies in the excellence of the natural drainage. The soils of the irrigated districts are generally porous and underlain with gravel through which the water filters away more or less rapidly. In cases where the substrata are impervious the slope of the land is usually so great that water will not stand long upon its surface. In regions where the soil and slopes are favorable to natural drainage the amount of water required for irrigation in order to produce a healthful growth of plants is necessarily somewhat increased—in other words, the duty of water is lowered. In those portions where the natural drainage is poorer, while the quantity of water required for irrigation is reduced to a minimum, the production of alkaline salts due to the evaporation of the water on the surface may result, necessitating artificial drainage for its prevention. In still other regions the result of standing water and defective drainage may destroy the value of the land for agricultural purposes by "swamping" or "water-logging" it, leaving pools of stagnant water upon the surface, and seriously affecting the health of the community by producing malarial and other fevers. In such regions artificial drainage must be at once employed. Other remedial measures, however, are a more careful use of water, employing only so much as is absolutely necessary for the production of crops and the reduction of seepage by a better construction of canal banks. There are certain limited areas, however, internal drainage basins to which there is no natural outflow, which it will always be impossible to irrigate.

In irrigating light soils very small streams of water should be used; otherwise, if the drainage is good, there is danger of washing out the soluble fertilizing elements, leaving only the coarse mineral constituents and rendering the soil less fertile and productive. This precaution is especially necessary when using the clear pure water from springs or artesian wells, which carries ordinarily little of the rich fertilizing sediment characteristic of streams which flow for long distances through alluvial regions. In the employment of the latter, if well charged with sediment, the use of a large irrigation head is frequently advantageous, as it gives an opportunity for a uniform settlement of the sediment while the water is entering the soil.

The following remarks on alkali and its causes are liberally quoted from a valuable report on the subject made by Prof. E. W. Hilgard:[1]

> The immediate source of alkali is usually to be found in the subsurface or soil-water, which, rising from below and evaporating at the surface, deposits there whatever of dissolved matter it may contain. Such water when reached by digging is by no means always perceptibly alkaline, and the same is mostly true of the soil a few inches beneath the surface, for, since the soil, acting like a wick, draws up the soil-water and allows it to evaporate at the surface, it is there that all the dissolved

---

[1] Alkali Lands, Irrigation and Drainage, E. W. Hilgard, Report University of California, Sacramento, 1886.

> matters accumulate until the solution becomes so strong as to injure or kill all useful vegetation. Obviously from the above considerations the more water that evaporates from the surface of the soil the more alkaline salts will be deposited on the surface. Hence within certain limits a greater rainfall will bring out a larger amount of alkali, or if, instead of rain, irrigation is employed the same effect will be produced.

This conclusion is unquestionably correctly drawn, providing these remarks are understood to apply to such lands as have faulty drainage, for were the drainage sufficiently free it is well known now that an increase of the volume of water applied to the soil causes the latter to carry down and away with it such salts as it takes into solution. The immediate and direct cause of the rise of alkali is the rise of the subsurface water level owing to defective drainage, which, thus reaching the surface from below by capillary attraction, is evaporated there. This would not occur were there drainage to carry the water off from below. Prof. Hilgard further says:

> While the corrosive action exerted by the alkali salts upon the root crowns and upper roots of plants is the most common source of injury, there is another kind of damage which manifests itself mainly in the heavier class of soils thus afflicted when the soluble salts consist largely of the carbonates of soda and potash. This is the great difficulty, or almost impossibility, of producing a condition of true tilth, in consequence of the now well-known tendency of alkaline solutions to maintain all true clay in the most impalpably divided or tamped condition, that of well-worked potter's clay, instead of the flocculent condition it assumes in a well-tilled soil.

The production of alkali as the result of evaporation varies naturally according to altitude, temperature, and drainage. Seepage from badly-constructed canals is one of the great producers of alkali. Where the velocity of the canal is too low, time is given for the water to soak into and permeate the soil, thus raising the subsurface water level. The same effect is produced by wasteful irrigation. Where conditions are sufficiently well balanced for drainage to prevent the rise of spring level to within, say, 10 feet of the surface, continued irrigation produces one excellent result by soaking up the lower strata and thus giving an abundance of water near the surface for wells and for the moistening of the deeper rooting plants. Neglect and ignorance of the principles governing the production of alkali have been most serious, and in a few portions of the San Joaquin valley in California and in India it has cost millions of dollars in the loss of lands and in the diminished demand for water.

There are some classes of water which it is not advisable to use for purposes of irrigation. Thus, it was at one time proposed to use the waters of Kern and Tular lakes in California for irrigation, but careful investigation showed that these waters were strongly alkaline and that their continued use would deposit on the surface a sufficient coating of salt to render the lands sterile. The beds of these lakes are coated with a deep stratum of alkali. Similarly some artesian waters, and even the waters from some flowing streams, like the Salt creek in northern Arizona, would result in the production of alkali. This subject of production of alkali was thoroughly investigated and reported by a commission sent by the British Government for that purpose to California after they had previously made a careful examination of the causes and remedies of alkali in India. Liberal extracts from this report have been made by me in a previous paper.[1] Among the more important conclusions reached by this committee were (1) that alkali was chiefly the result of defective irrigation by permitting evaporation of subsurface water, thereby leaving alkali on the surface, and (2) that the largest proportion of damage has been brought about by the rise of the subsurface water level by sidewise soakage from high line canals, and that the trouble has been greatly aggravated and extended by the extravagant use of water.

Numerous remedies for the removal of alkali and the methods of using lands covered with alkali have been recommended. Where it is impossible to entirely remove the alkali Prof. Hilgard recommends the cultivation of such crops as alfalfa, which is deep rooted and shades the soil, thus reducing the amount of evaporation. Deep and frequent tillage is essential for the removal of the surface crust of alkali, and as this condition can not be fulfilled in the case of broad-cast crops—that is, the cereals—these must ultimately be abandoned in alkali regions and superseded by hoed crops, which will admit of the ground being kept in perfect tilth throughout the season. One most effective method of preventing the production of alkali is the practice of subirrigation through pipes, which not only supply the water to the land, but at the same time act as drains. In a lesser degree the same result is obtained by the use of deep furrows or ditches, through which the water is allowed to flow, the soil being moistened by means of sidewise soakage. The great multiplication of these furrows and their interference with the operations of agriculture on the larger scales have, however, generally caused a restriction of the use of this mode of irrigation.

When the quantity of alkali is small, the evil effects resulting from its presence may be mitigated by the application to the soil of chemical antidotes. A cheap antidote for most alkaline salts is lime; in some cases neutral calcareous marl will answer the purpose. When the alkali consists of carbonates and borates, the best antidote is gypsum or land plaster. These materials should be sown broadcast over the surface and harrowed into a moderate depth prior to irrigating. In order that the proper antidote may be chosen it is necessary to determine by chemical analysis the variety of salt which is to be removed.

SILT AND SEDIMENTATION.

The great volumes of silt carried in suspension by a majority of the larger rivers and streams which flow through the great alluvial valleys of the West are heavily charged with silt during the several months of the year. This sediment is a result of the erosion of the alluvial banks of the river during the high and protracted floods which periodically occur. The Sacramento and San Joaquin rivers in California and some of their branches are noted for the volume of sediment carried in suspension, likewise the Colorado and Gila rivers in Arizona and their branches. Many of the streams in Colorado and, above all, the Rio Grande in New Mexico are always turbid and sometimes even viscous from the volume of matter which they carry in suspension.

---

[1] Irrigation in India, Herbert M. Wilson, Twelfth Ann. Rept. U. S. Geol. Survey, Pt. II, 1891.

Some investigations were made by the engineers of the U. S. Geological Survey in 1889, to determine the amount of sediment carried by the Rio Grande. It was proposed to construct a reservoir on this river, and it was desirable to find how long it would take to destroy it by silting. The sediment of the river during high water was frequently sampled and was found to range from one-fourth to one-half of one per cent of the volume of flow, the average of 118 samples being 0·345 of one per cent. On the whole it appeared that at least one hundred and fifty years would have to elapse before a reservoir 60 feet in depth would be seriously impaired by the sediment deposited. As to the effect of the sediment carried by rivers, very different results may be expected under different circumstances. The case just cited was one in which only the sediment in suspension was measured, while quantities of gravel and large stones were rolled along the bottom of the stream, and what the amount of this may be was not determined. In the case of the Rio Grande at El Paso it was doubtless small. On the American river at Folsom, in California, in one year a depth of nearly 30 feet of wet silt was deposited in the reservoir. In this case, however, the grade and velocity of the stream are very high, and it is probable that most of the matter deposited was coarse gravel, pebbles, and bowlders rolled along the bed of the stream.

The volume of this matter which is carried in suspension is so great, however, that in the course of a few years it will frequently impair the usefulness of reservoirs. In a majority of cases, especially in the lower reaches of the larger reservoirs, where the silt is light and fine and has been transported long distances, it will doubtless take many years for a sufficient amount to accumulate to seriously affect their storage capacity. Many devices have been tried to diminish this evil of silting, all more or less unsuccessful. Among these, which will be mentioned in detail in their proper places, are undersluices in the bottoms of dams for flushing them; the leaving open of undersluices in times of high floods, so that the heavy silt-laden water is permitted to pass on without settling; and the construction of cheap, small settling reservoirs above the main reservoir. This sediment enters the canals at their head gates, and may become a heavy charge if these are improperly constructed, so as to permit it to be deposited and retained in their beds.

The value of silt-bearing water as a fertilizing material is well known and appreciated throughout the world. Indian engineers endeavor to prevent the admission of silt to canals chiefly because the velocities in these canals are necessarily low as they are used for navigation. In the canals in Europe and America, however, whenever it is possible to keep the silt in suspension, silt-laden waters for irrigation are highly appreciated. Cases of injury from this source may be cited, however, as that of the Henares canal in Spain, which, though a fine piece of engineering work, has proven a partial financial failure, owing to the clearness of the water used. The land had been exhausted by crops, and the company found it necessary to reduce the water rates and improve the land by artificial fertilization. In the valley of the Moselle in France, on land absolutely barren and worthless without fertilization, the alluvial matter deposited by constant irrigation rendered the soil capable of producing two crops a year after a few years of use. The difference is very marked between the valleys and meadows irrigated with the silt-bearing waters of the Durance canals and those of the clear cold Sorgues, so much so that the cultivators prefer to pay for the former ten or twelve times the price demanded for the latter.[1]

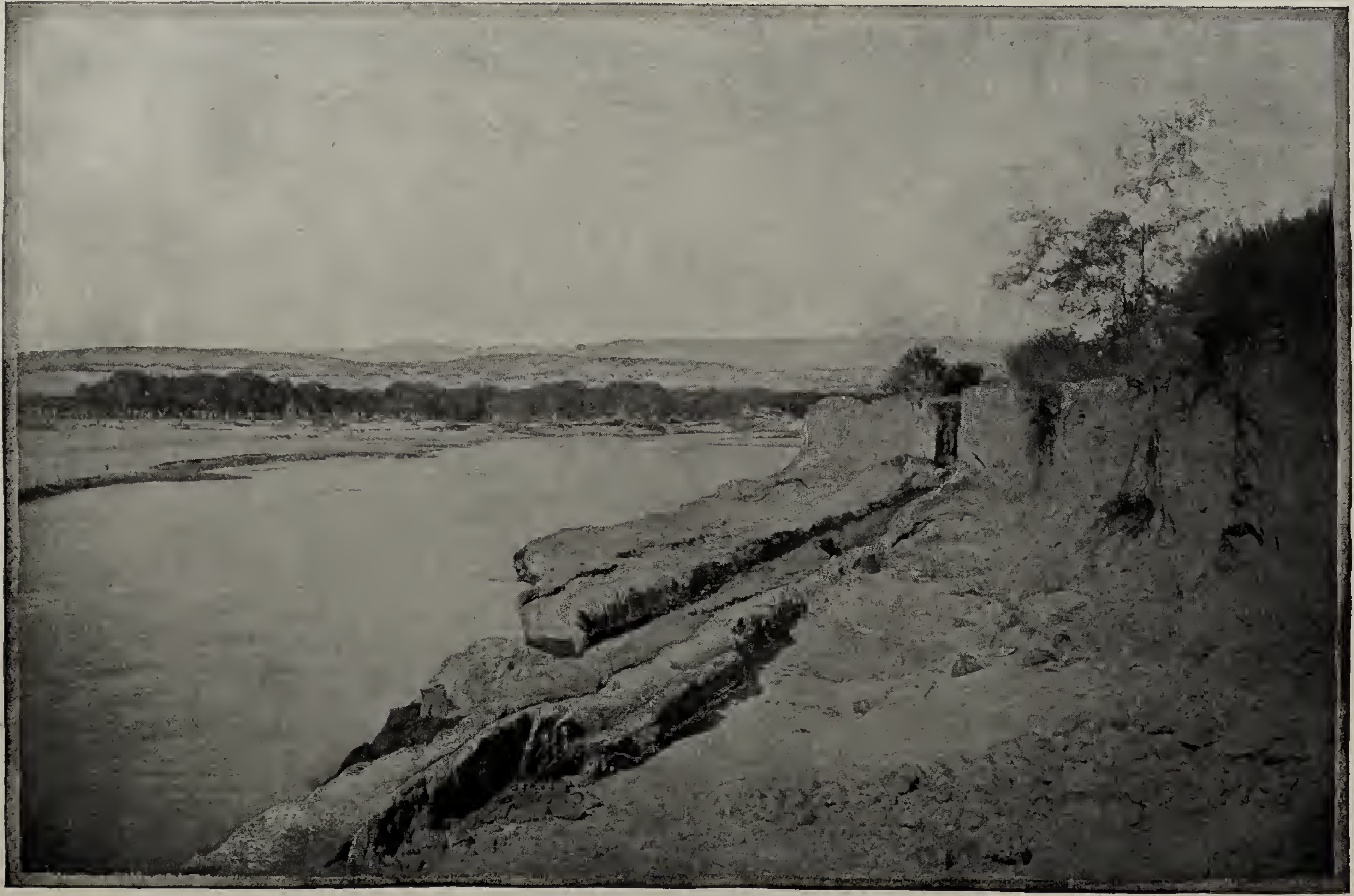
In Los Angeles county, California, the clear pure water used for irrigation, coming from artesian wells and springs, carries so little rich fertilizing sediment that it does not restore the elements of plant growth to the soil as does irrigation in some other parts of the state, where water is laden with silt. In the neighborhood of Folsom and near Smartsville, California, the sediment in the water used for irrigation has been retained on the surface, and has thus rendered fertile and productive lands which a few years ago were almost barren.[2]

Numerous other examples of the value of silt as a fertilizing material might be cited. These, however, are sufficient; but the fact must always be borne in mind that where silt-laden waters are used the canal must be so designed as to bear the silt in suspension to the agricultural lands and not deposit it in the bed of the canal.

---

[1] Irrigation in Southern Europe, Lieut. Scott Moncrieff, E. and F. N. Spon, London, 1868.

[2] Report, State Engineer of California, William Hammond Hall, Sacramento, California, 1880.



PUEBLO CANAL, VERDE VALLEY, ARIZONA.

CHAPTER II.

HISTORY AND LEGISLATION.

The first indications of irrigation in the United States are found in Arizona, which in many respects presents the most interesting field on this continent for the student of this industrial art. There is abundant testimony that in the remote past many of the barren and forbidding deserts of Arizona were covered with vegetation. In nearly every portion of the Salt and Gila river valleys the close observer will find traces of early habitation and of systems of irrigation, by means of which the broad plains and mesas were brought to the highest state of productiveness. Enough can yet be seen of these prehistoric works to show that they were constructed with no small amount of engineering skill, while the labor expended on the canals was immense. The valleys of the Verde, San Pedro, and other rivers also show unmistakable signs of former careful cultivation.

The age of these canals is entirely a matter of conjecture. When, in 1542, Coronado was seeking in the north for the "Seven Cities of Cibola," he discovered the ruins of Casa Grande in the Gila valley. The historian of the expedition, Castenada, described these ruins as follows:

> The remains of a large canal for irrigation were traceable from the river to the point at which it reached the plain on which the city of Casa Grande rested, and could be followed for a distance of 9 miles around the city with an average width of 10 varas (25 feet).

Mr. Frank Cushing, of the United States Bureau of Ethnology, while investigating the ruins of the Salt River valley, gave it as his opinion that perhaps between the eighth and ninth centuries this valley was densely inhabited by a population supported by agriculture.

Various careless writers on the subject of the Pueblo ruins give astonishing accounts of the hundreds of thousands of acres probably irrigated by these works, and enormously exaggerate their size and importance. There is no doubt, however, of their existence, and some of them were very large. One of the best preserved was examined and surveyed by Mr. Cosmos Mindeleff, of the United States Bureau of Ethnology, and will be described by him in the Thirteenth Annual Report of that Bureau. This canal, while not one of the largest in existence, is, perhaps, in as good a state of preservation as any, and its description by such an experienced ethnologist as Mr. Mindeleff renders the account of it more authoritative.

The canal is diverted from the Verde river below Camp Verde. Its exact length can not be ascertained, as it disappears in several places

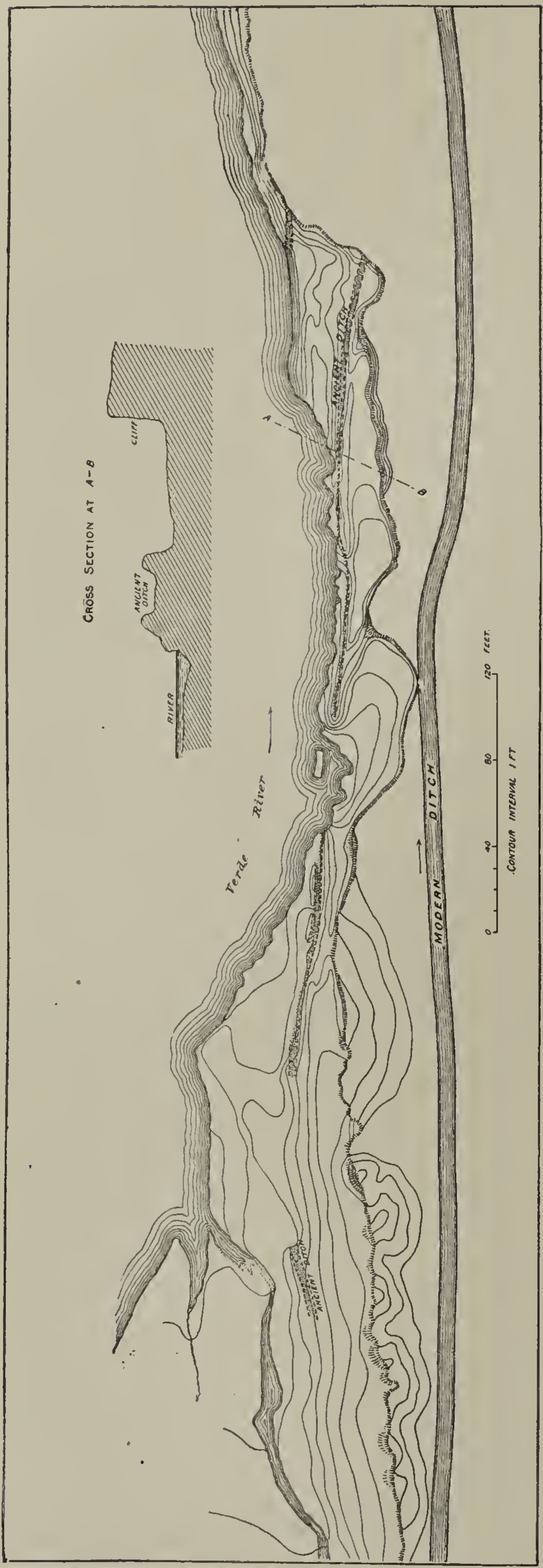


FIG. 64.—Profile of Pueblo canals, Verde valley, Arizona.

to reappear with greater distinctness in others. A sketch map and profile of its line are shown in Fig. 64 and a general view in Plate CXI. It is constructed on an alluvial bottom close to the water edge and below the gravel and alluvial bluff which rises about 10 feet above it and terminates the general level of the valley. This canal, about 5 feet wide at the bottom and 3 feet in depth, is laid out on an excellent grade, with a good straight alignment. At present the upper portion of it near its point of diversion from the stream is hidden by the recent river deposits which have widened out the bluff and covered the old canal. In 1891, however, in high flood, the river destroyed a portion of this bluff and exposed quite a length of canal which was heretofore hidden from view.

On Clear creek, below Camp Verde, Mr. Mindeleff examined a large bottom land laid out in windrows or minor irrigating channels running parallel to each other down the slope of the valley and built up and lined out with small stones.[1] The area of this piece of land is about 1,200 acres, and it was formerly a well-cultivated field into which a ditch was diverted from Clear creek. This ditch is neither wide nor long, and in places is well preserved and shows evidences of good judgment in alignment and grades. On its line is a small distributing reservoir about 60 feet in diameter and 6 feet in depth. This reservoir is not in a natural depression, but is an artificial excavation, the gravel taken from its interior having been thrown out to form the banks, which thus stand somewhat above the level of the valley. Lower down the Verde river, about 20 miles north of Fort McDowell, is a larger ditch about 14 feet wide and cut for some distance through gravel and bowlders. All of these works are constructed in easily workable material, as alluvial deposits or gravels.

---

[1] Thirteenth Annual Report Bureau of Ethnology. J. W. Powell, Director, Washington, D. C., 1892.

Between the Salt and Gila rivers, near Marysville, is a plain 30 miles long and 4 or 5 miles wide, most of which was under cultivation at one time, as indicated by the remains of many canals. Near Phœnix are the remains of an old canal which was perhaps 20 feet wide and 20 miles long. Near Tempe, opposite Phœnix, are the ruins of several rather important irrigation canals. In one of the largest of these old works, the Mesa canal, near Mesa city, a little east of Tempe, a portion of the bed is now used for irrigating and for supplying the neighborhood of Mesa city with water. Its water is taken from the south bank of the Salt river, about 25 miles east of Phœnix, and runs for several miles through hard volcanic rock. The canal was excavated through this rock to a depth ranging from 20 to 30 feet for a distance of several hundred feet, and must have been cut without the aid of explosives of any kind. The width of the canal was about 20 feet and its capacity probably 150 second-feet. The evidence of the chipping process by which the rock excavation was made is very distinct; while great numbers of worn-out stone axes and hammers are to be found along the canal at this point for several miles, mute evidences of the long and arduous task. It was this old canal which convinced the early Mormon settlers of the practicability of diverting the water of the Salt river at this point, and which resulted in the formation of the colony and the establishment of the first white settlement in that neighborhood.

On the Hassayampa river, a number of miles northwest of Phœnix, are the strongest evidences of the great length of time during which this system of irrigation was maintained. A canal from this river traverses a "malpais" mesa for several miles and falls abruptly into a valley 40 or 50 feet below. Where this fall occurs the water of the canal has cut away for several feet the walls of the mesa. As these are of hard volcanic rock and every evidence indicates that the attrition of the water alone has effected this result, centuries must have been required for the work. Much more valuable information is now being gathered by the Ethnological Bureau concerning these ancient irrigation works, and the reports will add materially to our knowledge of their extent and character.

The early Spanish settlers were the first civilized people to cultivate by means of irrigation. In all probability they first introduced irrigation into the United States, in the vicinity of the old San Diego Mission in California. One of the first things which the Padres did when establishing themselves there was to undertake cultivation by means made familiar to them by their knowledge of irrigation practice in Spain and Mexico. With the aid of their first Indian converts a dam was thrown across the San Diego river, and the water was diverted to the adjacent bottom lands and mesas. The remains of these works show the diligence of their long-forgotten constructors. On San Bernardino creek are found some of the remains of one of the oldest irrigation systems in California. In 1797 the mission of San Fernando was founded and the water of the creek and one of the "Cienegas" was used for producing crops and cultivating trees and vines. There are still to be seen the remains of a couple of masonry dams and a pipe line, made of burnt tiles, used in irrigation nearly one hundred years ago.

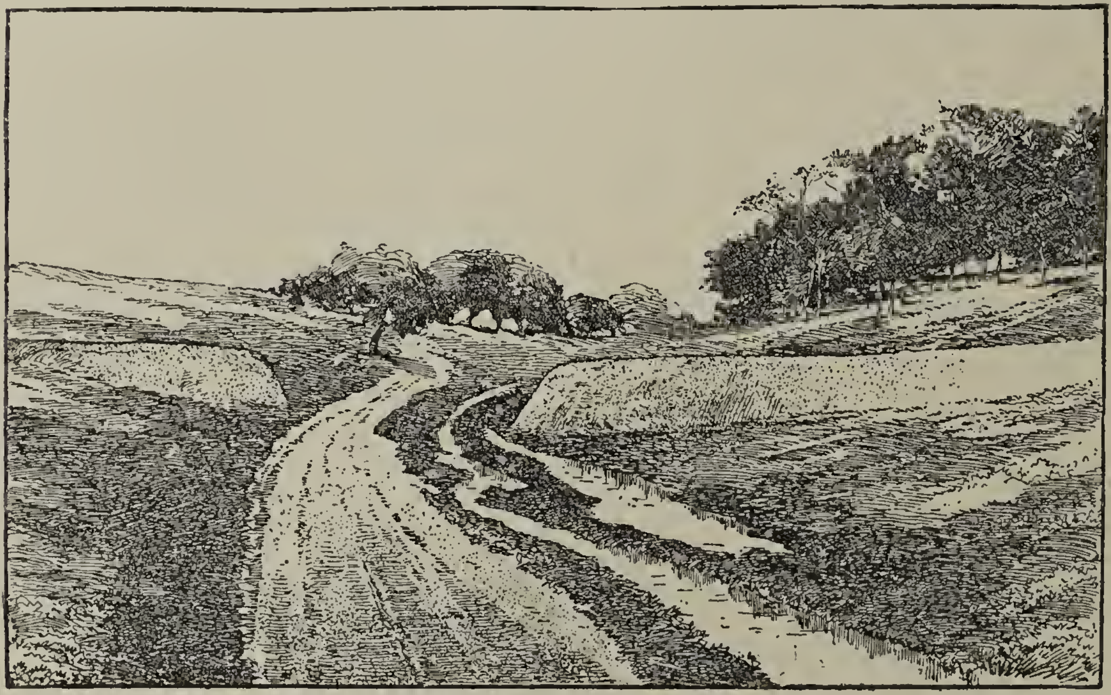


FIG. 65.—Ancient dam, San Luis Obispo county, California.

In southern Los Angeles county, in the valley of the San Juan, is ocated the old mission of San Juan Capristrano, next to San Diego, the site of probably the oldest irrigation development by civilized people in this country. The mission was founded in 1776, and water was in the same year diverted from the river and a large area put under cultivation. At Santa Barbara are the remains of an irrigation system planned by the Padres; a massive stone dam still remains in perfect condition, and traces are to be found of the stone canal and pipe lines of burnt tile in which the water was conducted along the hillside from a reservoir to the open plain, where it was utilized in cultivating crops. A masonry dam is still in use and forms part of the system by which the city of Santa Barbara is supplied with water for domestic use. Fig. 65 shows the remains of an ancient dam used for irrigating purposes in San Luis Obispo county, in California.

In Arizona, and particularly in New Mexico along the Rio Grande, the early Mexican settlers practiced irrigation in a rude way quite extensively, and the whole of the valley of the Rio Grande is still dotted with farms and settlements, the cultivation of which is by means of irrigation from that river. In no case are any of these ditches of sufficient size to be worthy of description. All are comparatively small and crude affairs, but they or their kind have been in constant use in that region since the earliest settlement by the Mexicans, dating back to the time of the settlement at Santa Fé, over three hundred years ago.

We must credit the Mormons with being the first Americans to adopt the practice of irrigation as an aid to agriculture. According to the statement of President Milford Woodruff, made before the Irrigation Congress recently held in Salt Lake City, the Mormons, immediately upon their settlement in Utah, in 1847, discovered that it would be impossible to raise crops with the small rainfall occurring in that region. They hit upon the idea of utilizing the waters of City creek and other streams to aid in maturing their crops, and they soon learned to do this most conveniently by diverting the water from the streams and by constructing ditches to lead them onto the fields. From these early beginnings they went on improving their methods and increasing their canals and ditches, or building small reservoirs as settlement increased, until the present thorough system of cultivation by irrigation was reached. The methods of the Mormons, though at first extremely crude, were the development of their own resources.

At about the same time the early American settlers on the Pacific coast, taking their lessons from the methods employed by the Mexicans, commenced the cultivation of small farms and vegetable patches, and as mining ditches were extended and the necessity created for the cultivation of vegetables and fruits for the sustenance of the miners, the practice of farming became more common. In fact, in California the first irrigation was from mining ditches, and until within the last few years much of the irrigation practiced in the foothills of the Sierras was by means of old abandoned mining ditches, which were utilized for transporting water for purposes of irrigation.

One of the oldest irrigation works undertaken by Americans was that of the Duarte district in southern California. Water was diverted by the Padres from the San Gabriel river as early as 1821 and carried in a ditch to the San Gabriel mission. In 1854 the owner of the Duarte ranch constructed a ditch and took out water for irrigation on his property, and from these beginnings developed in 1882 and was consummated in 1884 the present system of irrigation in that neighborhood. In 1821 water was diverted from Mill creek, in San Bernardino valley, by the Padres and crop raising by irrigation extensively practiced. The Mill creek ditch which is so extensively used on the valuable fruit ranches of San Bernardino to-day was, so far as known, located in that early day and yet remains unchanged.

All of the more modern works of southern California, as the Gage canal and similar works in the neighborhood of Riverside, and the Bear valley reservoir in San Bernardino county, have been undertaken since 1880. In that year the state engineer, William Hammond Hall, made surveys for a canal which is substantially that now known as the Gage canal begun in 1885. At about the same time in 1881 Judson and Brown commenced their real estate operations in the neighborhood of Redlands and diverted the water from the Santa Anna river for purposes of irrigation, and about 1883 Mr. Frank Brown discovered the present site of the Bear valley reservoir and commenced to lay his plans for the construction of that work. The San Diego Flume Company's works and the Sweetwater reservoir in southern California are of recent construction, both having been started about 1886.

The present system of great canals through the upper San Joaquin and Sacramento valleys may be said to have had its beginning in the early seventies, though up to that time irrigation had been practiced in a small way and had attracted the attention of the government. The President of the United States appointed a commission in 1874 to report on the irrigation of the San Joaquin, Tulare, and Sacramento valleys in California.[1] The report of this commission and a later report on irrigation in Europe and India, made by Prof. George Davidson of the Coast Survey,[2] are two of the mile posts which mark the awakening of the people of California and the country at large to the subject of irrigation and the necessity of learning the best methods of practicing it.

In 1873 there was published by Mr. Isaac Friedlander, of Sacramento, a short pamphlet on Irrigation in California.[3] This pamphlet reviewed the prospects of the development of irrigation in that State and noticed some of the large works being constructed by a few enterprising capitalists. At that time there had been constructed or were under construction several of the larger canals which are still in constant service in the San Joaquin valley. Among these are the Fresno canal, The People's canal, the Farmers' canal of Merced, the San Joaquin and Kings river canal, the Musselslough canal, and others. While of considerable magnitude and commanding great areas of land, the works on these canals are lacking in the qualities of permanence and in the essentials of good location which characterize later works. The dams and headworks usually consisted at first of brush or stone thrown across the river channel, while slopes and grades given to the canal were such that their banks were rapidly eroded and destroyed and as much money has perhaps been expended in their maintenance and the correction of errors as in their first construction.

---

[1] Report of the Board of Commissioners on Irrigation; Government Printing Office, Washington, 1874.

[2] Irrigation and Reclamation of Land for Agricultural Purposes in India, Egypt, etc. George Davidson; Government Printing Office, Washington, 1875.

[3] Irrigation in California; Sacramento, Cal., 1873.

Irrigation was first practiced in Colorado about twenty-five years ago, when some of the pioneers abandoned gold digging for the more profitable industry of agriculture. The practice was forced upon them by repeated failures in attempting to raise crops with a deficient rainfall. The result has proven a blessing, however, for instead of contending with drought and loss of crops, they planted and harvested without fear by the aid of irrigation, and some of these early pioneers are to-day among the wealthiest farmers in Colorado. The development from the earlier crude ditches built by the ignorant irrigator to the elaborate systems resulting from riper knowledge has been similar to that already outlined for California and other portions of the West. In 1860 the first attempt to build a large ditch in Colorado was made by a few citizens of Denver, who spent about $10,000 in a ditch on which their incompetent engineer failed to give any fall. Two years later the Platte Water Company's ditch was built and is still in operation, and supplies Denver with some of its irrigation water. Between 1862 and 1880 a great many ditches were constructed, but all were on a small scale. The development of large tracts of land by extensive canals was begun by the English Company, whose first enterprise was the Larimer and Weld canal, still one of the largest in Colorado, The same management commenced the construction of the Highline canal in 1880, and completed it in 1883. This canal takes its water from the Platte river and irrigates land in the neighborhood of Denver. It was followed by the Loveland and Greeley canal and the North Poudre canal upon the eastern slope of the mountains near Denver, and by the construction of the Del Norte and other large canals in the San Luis valley.

LEGISLATION AND ADMINISTRATION.

Unlike that of foreign countries, the administration of the irrigation works of the United States is conducted exclusively by private parties. Until recently the legislation enacted on the subject of irrigation was universally imperfect in this country. It is yet far from what could be desired. In a majority of the arid states little or no legislation has been enacted of the kind that is necessary for the mutual protection of the irrigation companies and the irrigators. In California and Colorado, and more notably in Wyoming, legislation has been enacted which covers many important features calling for attention. In most of the other states little legislation has been enacted for the protection and encouragement of irrigation.

California, Nevada, Oregon, and a few other Western states, have no constitutional provisions affecting the public use of water for irrigation. In these and other states, however, issues involved have frequently been acted upon by courts. As a result, there has grown up from the necessities of the case a great body of law and judicial interpretation, much of which is extremely involved and ambiguous As a general thing throughout the West the old common-law doctrine of riparian rights is not in force. The principle of prior appropriation, as wrought out by the earlier miners and embodied in the federal law and the laws of the states and territories, is steadily sustained by the courts as the common law of the arid regions.

Colorado was the first state to enact constitutional amendments embodying legislation on the public nature of water rights and obligations. In these constitutional amendments the water of every natural stream not theretofore appropriated is declared the property of the public; it is further provided that the right to divert the unappropriated waters of any natural stream for beneficial uses shall never be denied, priority of appropriation being held to establish prima facie rights; private property is authorized to be taken for private use for reservoirs, drains, flumes, etc., across all lands, if just compensation be made; private persons and corporations are given the right of way across public, private, and corporate lands for the construction of ditches, canals, etc. In addition to these general constitutional provisions a great many statutes have been enacted. The constitutions of Idaho, Wyoming, and Montana contain provisions similar to those of Colorado. In Dakota, Washington, New Mexico, and some other states a constitutional enactment has been passed, but the legislation is not so full or comprehensive as that alluded to above. The majority of these states have based their constitutional amendments and legislative statutes upon the experience of Colorado and California. Of all these, Wyoming has profited most by the experience of its predecessors. The laws of that state are more modern and enlightened in their provisions, and attain more nearly the highest theoretical standard, than those of any other State. For this Wyoming is largely indebted to her present state engineer, Mr. Elwood Mead, and to U. S. Senator F. E. Warren.

The constitution of Wyoming declares that water being essential to industrial prosperity, of limited amount and easy of diversion from its natural channel, its control must be in the State, which in providing for its use must equally guard all of the various interests involved. The various sections in the constitution following this declaration of rights are similar to those of Colorado, and further provide that property shall not be taken for private use without the consent of the owner, except for private ways, reservoirs, ditches, etc., and then only after making due compensation; and that the water of all natural streams, springs, and lakes within the boundary of the state are the property of the state. Most important of all, they provide that there shall be constituted a Board of Control, to be composed of the state engineer and the superintendents of the water divisions, which shall have the supervision of the waters of the state and of their appropriation, distribution, and diversion, its decisions to be subject to review by the courts of the state. Priority of application for beneficial uses is given the better right. The legislature is directed by law to divide the state into four water divisions and to provide for the appointment of superintendents therein. A state engineer is provided for, who shall hold his office for a term of six years. He shall be president of the board of control, and shall have the general supervision of the water of the state and the offices connected with its distribution.

As yet the government of the United States has enacted little legislation for the protection of irrigators or of corporations intending construction. The government, however, has in recent years done a great deal for the encouragement of irrigation by directing investigations in various channels and making provision for surveys and experiments on the more important abstract questions relating to irrigation. The irrigation branch of the U. S. Geological Survey was created by law in 1888, and continued for over a year to do work both in the field and in office. The Agricultural Department has made careful investigations of the subject of artesian waters and the possibility of developing these sufficiently to render them of value for purposes of irrigation. In the act making appropriations for sundry civil expenses for the fiscal year ending June 30, 1889, approved October 2, 1888, provision was made for the survey of the arid lands. This law provided for the investigation of the extent to which the arid region could be redeemed by irrigation, for the segregation of irrigable lands, for the selection of sites for reservoirs and other hydraulic works necessary for the storage and utilization of water for irrigation, and for the necessary maps. This work was to be performed by the U. S. Geological Survey, under the direction of the Secretary of the Interior.

Appropriations were made for the fiscal years ending in June, 1889 and 1890, and the work was prosecuted with vigor. The following Congress, however, failed to make appropriations for the continuance of this work and little has been done since, beyond the completion of reports and the segregation of reservoir sites by the topographic field parties of the Geological Survey. The clause contained in the bill above cited which provided for the segregation and withdrawal from sale or occupation of irrigable lands was repealed by act of Congress passed in the spring of 1891. A further act, however, passed during the same Congress and approved March 3, 1891, made some regulations and provisions regarding the mode of obtaining and settling on public lands which, while it does not go as far as the act segregating irrigable lands, prevents the wholesale occupation of the same by corporations or speculators.

Among other things, this act provides that the party filing a declaration shall also file a map of the land, which shall exhibit a plan showing the mode of contemplated irrigation and one which shall be sufficient for the accomplishment of the purpose. This plan shall also show the source of the water to be used for irrigation and reclamation.

Provision is also made that no land shall be patented to any person under this act unless he shall have expended in the necessary irrrigation, reclamation and cultivation at least $3 per acre of the whole tract reclaimed and patented in the manner following :

> Within one year after making entry for such tract of desert land as aforesaid the party so entering shall expend not less than $1 per acre for the purposes aforesaid; and he shall in like manner expend the sum of $1 per acre during the second and also during the third year thereafter, until the full sum of $3 per acre is so expended. Said party shall file during each year with the register, proof, by the affidavits of two or more credible witnesses, that the full sum of $1 per acre has been expended in such necessary improvements during such year, and the manner in which expended, and at the expiration of the third year a map or plan showing the character and extent of such improvements. If any party who has made such application shall fail during any year to file the the testimony aforesaid the lands shall revert to the United States, and 25 cents advanced payment shall be forfeited to the United States, and the entry shall be canceled. Nothing herein contained shall prevent a claimant from making his final entry and receiving his patent at an earlier date than hereinbefore described : *Provided,* That he then makes the required proof of reclamation to the aggregate extent of $3 per acre: *Provided,* That proof be further required of the cultivation of one-eighth of the land.

Prior to the passage of the above, other acts were passed in the fall of 1890 to prevent any one settler from acquiring title under the land laws to more than 320 acres in the aggregate under all of the laws, thus reducing the amount of land which can be obtained by one settler from 1,120 to 320 acres. A later act repealed the timber-culture and preemption acts so that at present no one settler can acquire a title to more than 320 acres, and this only under the homestead and desert entry acts, or the latter alone. The last law above cited so modifies the desert-land acts as to compel those settling under them to show a genuine intention to irrigate.

The same act of March, 1891, from which the above extracts were taken, provides that reservoir sites located or selected under the provisions of " An act making appropriations for sundry civil expenses of the government for the fiscal year ending June 30, 1889, and for other purposes," shall be restricted to so much land as is actually necessary for the construction and maintenance of reservoirs; that the right of way through the public lands and reservations of the United States shall be granted to any canal or ditch company formed for the purpose of irrigation and duly organized under the laws of any state or territory which shall file with the Secretary of the Interior a copy of its articles of incorporation and due proofs of its organization, to the extent of the ground occupied by the water of the reservoir and of the canal and of its laterals, and 50 feet on each side of the marginal limits thereof; also the right to take from the public lands adjacent to the line of the canal or ditch, material, earth, and stone necessary for the construction of such canal or ditch. All maps of location shall be subject to the approval of the department of the United States government having jurisdiction over such reservation.

This act further provides that any canal or ditch company desiring to secure its benefits shall, within twelve months after the location of 10 miles of its canal, file with the register of the land office a map of its canal or ditch and reservoir; and upon the approval of the Secretary of the Interior the same shall be noted upon the plats in said office, and thereafter all lands shall be disposed of subject to such right of way.

Provided, That if any section of said canal or ditch shall not be completed within five years after the location of said section, the rights herein granted shall be forfeited as to any uncompleted section of said canal, ditch, or reservoir, to the extent that the same is not completed at the date of the forfeiture.

The above enactments make it possible for settlers to obtain title to reservoir sites and right of way for irrigation works over government lands without payment for the same, and by merely filing on the land and fulfilling the requirements of the law.

In order that the condition of irrigation legislation in this country may be better understood, further reference will now be made to the operations of the state laws in Colorado, California, and Wyoming, as in these states the most progressive laws have been enacted. The laws of Wyoming are very similar to those of Colorado and are modeled after them, but important modifications and changes have been made which render them far superior. It is difficult to say whether the laws of California are better or worse than those of Colorado. They are essentially different and distinct in their character and operations from those of the middle arid regions. They are an outgrowth and a result of the fertility of the soil of California and the lesser aridity of its climate. In California nearly all of the available irrigable lands were already owned, settled, and cultivated or otherwise utilized prior to the passage of its irrigation laws. The laws which are referred to here are included in the "Wright bill" and in a general way provide for the formation of irrigation districts and the bonding of the lands within these districts to defray the expenses of constructing the irrigation works. Such a law can have value and force only where the land already has a market value sufficient to induce capitalists to invest in the bonds. Most of the lands of California fall within this condition. In Colorado, Wyoming, and elsewhere, however, the market value of the lands is so low and the settlement on these prior to irrigation is so sparse that such a law as that of California would be of doubtful utility. It is not likely that the bonding of the lands of those states would realize a sufficient sum to defray any appreciable proportion of the expenses of constructing irrigation works.

The laws of Colorado are deficient in several of the essentials to their proper operation, as pointed out in a paper recently read before the Denver Society of Civil Engineers.[1]

---

[1] Anderson, G. G.: Some Aspects of Irrigation, Transactions Denver Society of Civil Engineers, vol. 1, 1890, Denver, Colorado.

The state of Wyoming has made several improvements on the Colorado laws. To begin with, the state engineer receives a good salary and is appointed for a term of six years. His duties are prescribed as follows:

> SEC. 9. The state engineer shall perform such duties as are prescribed in the law defining the duties of the board of control, and, in addition, shall make, or cause to be made, measurements and calculations of the discharge of streams, from which water shall be taken for beneficial purposes, commencing such work upon those streams which are most used for irrigation or other beneficial purposes. He shall collect facts and make surveys to determine the most suitable location for constructing works for utilizing the water of the state, and to ascertain the location of the lands best suited for irrigation. He shall examine reservoir sites and shall, in his reports, embody all the facts ascertained by such surveys and examinations, including, wherever practicable, estimates of the cost of proposed irrigation works, and of the improvement of reservoir sites. He shall become conversant with the waterways of the state, and the needs of the state as to irrigation matters, and in his reports to the governor he shall make such suggestions as to the amendment of existing laws, or the enactment of new laws, as his information and experience shall suggest, and he shall keep in his office full and proper records of his work, observations, and calculations, all of which shall be the property of the state.

The state is divided into four great water divisions, over each of which is a superintendent appointed by the governor, with the consent of the senate, and who shall hold office for four years. The division superintendents have general control over the water commissioners in their districts; they execute the laws relative to the distribution of water under the general supervision of the state engineer, and they make regulations to secure the equal and fair distribution of water. From their decision, however, anyone can appeal. A board of control is constituted, composed of the state engineer and the four water superintendents. They are directed to determine the priorities for the use of public waters in the state, to take testimony and adjudicate claims for appropriations, and to take measurements of streams. In determining the order of priorities the board of control is directed to make record of the same according to the time when it was made and the amount of water which shall have been applied for, for beneficial purposes. It is provided, however, that the appropriator shall not at any time be entitled to the use of more water than he can make a beneficial application of on his lands and that no allotment shall exceed one-second foot for each 70 acres of land for which appropriations shall be made. If there is any unappropriated water in the source of supply named in the application, the state engineer is required to approve the same. If there is no unappropriated water, or if in the judgment of the state engineer the appropriation is detrimental to public interests, he is directed to refuse the application.

The state is divided further into water districts, for each of which there is appointed a water commissioner, who shall hold office for two years, and whose duty it is to divide the water in the natural streams of his district among the several ditches, taking water therefrom according to the prior rights of each. The water commissioner is given power to arrest persons offending and to turn them over to the sheriff of the proper county. It is their duty to see that the proprietor of any public water shall maintain a substantial head gate at the point where the water is diverted, which shall be of such construction that it can be locked and kept closed by the water commissioner; and such proprietor shall construct and maintain when required a flume or measuring device, as near the head of the ditch as practicable, for the purpose of assisting the water commissioner in determining the amount of water diverted. The water commissioner is empowered to construct such device at the expense of the proprietor, providing the latter neglects to do so.

One of the important provisions in the state laws of Wyoming is the following:

> SEC. 48. Any person, association or corporation hereafter intending to construct any dam for reservoir purposes, or across the channel of any running stream above 5 feet in height, shall, before beginning the construction, submit the plans for the same to the state engineer for his examination and approval, and no dam above 5 feet in height shall be constructed until the same shall have been approved.

This provision is perhaps one of the best of those contained in the Wyoming law, and may do much good by preventing the construction of insecure works and the loss of life and property resulting from their destruction by floods.

The irrigation law of the state of California, known as the Wright act, because it was introduced by the Hon. C. C. Wright, of Modesta, California, was approved on March 7, 1887. This law provides for a district system of organization, under which the people in any given section, the lands of which are irrigable from a common source, may form an irrigation district similar to all intents and purposes to a municipal corporation. Having determined upon the source of supply and the most feasible manner of constructing the necessary works, surveys are made and estimates submitted of the cost of such work, and the people interested are empowered to vote bonds to defray that cost. These bonds are a first lien on all the property in the district, and the payment of the interest thereon and their redemption is to be made through taxes regularly levied and collected. Such a security as this possesses features scarcely surpassed by any other, as it becomes in reality a first-mortgage bond on all the lands of the district. Unlike money loaned upon mortgages, the proceeds of these bonds are directly devoted to the enhancement of the value of the original security, thus giving them an added value which is unsurpassed by any other form of bond. Since the passage of the Wright law over thirty-one irrigation districts have been organized and bonds to a large amount have been issued. In some cases these securities have been used in payment for water rights of irrigation works already constructed, but in a majority of instances the proceeds of the bonds are to be directly devoted to the construction of necessary works. The following table shows a list of the irrigation districts and their location:

District.	County.	Number of acres.	Bonds voted.	Bonds sold.	Bonds per acre.
Alessandro	San Bernardino	25,000	$765.000	$765,000	$30·00
Cirus Belt	do	11,700	800,000	800,000	68·37
East Riverside	do	3,600	250,000	100,000	83·33
Grapeland	do	10,787	200,000	None	18·54
Rialto	do	7,200	500,000	500,000	69·44
Elsinore	San Diego	11.300	None	None	....
Escondido	do	12,814	450,000	None	35·12
Fallbrook	do	12,000	None	None	....
Murrieta	do	15,600	None	None	....
Perris	do	22,800	442,000	252,000	19·48
Spring valley	do	22,000	None	None	....
Big Rock creek	Los Angeles	30.000	400,000	150,000	13·33
Pomona Orange Belt	do	4,500	200,000	None	44·44
Vineland	do	4,500	50,000	50,000	11·11
Santa Gertrudes	do	2,600	None	None	....
Anaheim	Orange	32,500	600,000	None	18·46
Orland Southside	Colusa	25,000	None	None	....
Central	do	156,550	750,000	286,000	4·78
Kraft	do	13,500	80,000	None	5·93
Colusa	do	100,000	600,000	None	6·00
Tulare	Tulare	36,719	500,000	150.000	13·61
Poso	Kern	40,000	500,000	250,000	12·50
Kern and Tulare	Kern and Tulare	84,335	700,000	350,000	8·60
Madera	Fresno	305,000	850,000	None	2·78
Alta	Fresno and Tulare	129,927	675,000	416,000	5·19
Sunset	do	363,400	2,000,000	None	5·50
Selma	do	271,000	None	None	....
Modesto	Stanislaus	81,500	800,000	142.000	9·81
Turlock	Stanislaus and Merced	176,210	600,000	422,500	3·40
Browns Valley	Yuba	43,000	110,000	100,000	2·56
Total		2,055,042	12,822,000	4,733.500	....

The underlying idea of the California system is that the water, being naturally scarce and imperatively necessary, should remain the property of the community requiring the beneficial use of the same. This law recognizes that capital is a necessity and aims to obtain it by means of the credit of the district to be benefited. Under all circumstances the works and the distribution of the water remain in the hands of the municipal body known as the irrigation district which has the additional power of levying rates and enforcing the same. The chief provisions of the Wright law are as follows:

> Whenever fifty landowners or the majority of those in a given district petition the county supervisors for the formation of a district, a hearing must be granted, and if the lands are all susceptible of one method of irrigation and the petitioners accompany their petition with a good and sufficient bond, double the amount of the probable cost of the organization of the district, the petition shall be granted and a district formed.

The irrigation district is divided into five divisions and one director elected from each, and these manage the affairs of the district as the directors of a corporation manage its affairs. Bonds are issued on the entire property in the district, and if they are not sufficient assessments can be levied through the supervisors and county officers. In addition to the five directors, who are elected biennially, there are also elected an assessor, a collector, and a treasurer, the other officers of the board of directors being elected from their number. The board of directors is compelled to hold regular monthly meetings, and all of its records are open to the inspection of any elector of the district. The board and its agents have the right of entry upon any lands in the district to make surveys, and may locate the line of any canal or branches on any lands which may be deemed best for the purpose. The board has also the right to acquire, either by purchase or condemnation, all lands and waters necessary for the construction, use, and maintenance of the works projected. It may construct the necessary dams, reservoirs, and works for the collection of water, and do any other lawful work in order that sufficient water may be furnished to each land owner in the irrigation district. Estimates of the amount of bonds necessary are made by the board of directors of each district and include the cost of right of way and construction. No sale of bonds, however, is permitted at less than 90 cents on the dollar. The board of directors is empowered to fix rates of toll and charges, and collect the same from all persons using the canal for irrigation and other purposes. The fact that the bonds are issued in installments has interfered with the sale, but investors are coming to understand the value and position of district bonds, and they are now finding a market.

As described by the author of the bill, the formation of an irrigation district is effected in substantially the same manner as other public corporations are organized in the state of California. This corporation has but a single purpose, the irrigation of all lands within the municipality. The same power which a county possesses to obtain and adopt plans for the construction of any public work is possessed by a district engineer. It is made the duty of the board of directors to employ a competent engineer, and cause an exhaustive examination to be made, to the end that the best of many possible systems may be determined. If the board adopts the plans presented by the engineer, they are submitted to the electors of the district, and the question of the issuance of the bonds is settled by them. When the directors adopt the report of the engineers, accompanied by specifications and details, the construction of the works is submitted to competent bidding, and the contractor, as is customary, is required to give a satisfactory bond for the completion of his work according to the adopted plans and specifications. Thus the district acquires the water at cost as nearly as possible. The landowner is not subject to annual exactions from those who deal out water as an article of merchandise and is not subject to the chance of not getting it in consequence of the failure of the seller to fill his contract. The landowner, in other words, owns the water and a sufficient amount of it for the irrigation of his land. In addition to this it becomes a permanant appurtenance to his land, and a part and parcel of his holding.

Unfortunately, after the law had gone thus far, an obstacle was encountered in the shape of a general popular ignorance regarding the value of irrigation bonds, and difficulty was encountered in disposing of them. With the multiplication of irrigation districts came the necessity felt at financial centers for definite and authentic information concerning each. The bankers of California, to whose judgment constant appeal was being made by contemplating bond purchasers, were daily applied to for information, which they were unable to give. This condition of affairs was proving a serious drawback to placing district securities. The difficulty has been largely remedied by the formation of a state association of irrigation districts. This association has elected officers and appointed a consulting engineer and legal advisers. It is the duty of the consulting engineer to examine and report on the question of water-supply plans and estimates for the works, the suitability of lands, and the general physical engineering and business questions involved in each district scheme. The legal advisers of the state association are required to report upon the legality of the issuance of bonds of the various districts.

It is regarding water-right deeds that the least and most lax legislation has been enacted. It is but just to the companies who construct expensive works that they be permitted to charge a fair amount for the use of the water which they furnish. There should, however, be proper restrictions placed on their charges, and such legislation should be enacted as would prevent them from oppressing unfortunate irrigators who from force of circumstances may be placed at their mercy. It is fortunate, however, that competition and the large quantities of yet unoccupied land and water in our West serve to prevent the abuse of this liberty. It would be of little avail for a water company to charge such extravagant prices for its water or its land as would prevent settlers from making a living. The water companies are thus compelled to make their charges as low as possible in order to encourage settlement. It is difficult to fix charges for water rights or water rentals. In a country requiring irrigation the annual rental of water, if put at a price low enough to encourage settlement, will not pay 1 per cent above operating expenses for several years. The failure of the company is the last thing which the landowner desires to see, for the result would at once become evident in the depreciation of land values. If the company sells its water rights too cheaply and its income is insufficient, one of the first results will be the running down of the works and bad service to the settlers.

Irrigation companies are therefore compelled to make contracts in advance for the water which they will furnish. They provide for payment in cash, in mortgages or in land or labor. The landowner receives a long time or perpetual contract entitling him to purchase so much water during the period contracted for, and in any case the stipulated amount of water is attached to the land in such a manner that it can not be taken away without the consent of both parties. These contracts or water rights in most cases convey only the privilege of paying for the use of so much water in connection with the land. A water right in fact is a paid-up insurance policy. It means that if the water can be furnished the holder of the water right will have equal title to purchase it with any other holder of a water right, and companies are not supposed to sell more rights than they have water. In this particular, however, the law is lax. There should be some provision made whereby the operations of water companies can be supervised and they can be prohibited from disposing of more water rights than they have water to satisfy. In some states this is so, and in general the companies would find it difficult to sell a larger number of rights than they could fill, though several instances of such transactions could be cited. As a general thing water rights are now sold rather in proportion to the maximum capacities of canals than to their minimum discharges. Parties so desiring should be able to purchase more water than stipulated in their water right, provided the company has it at its disposal, as in seasons of abundance, but no absolute rights should be sold for more than the minimum for low water seasons.

It is accordingly seen that a specified sum of money must be paid for the privilege of a water right. These water rights are sometimes sold separately to settlers owning land; in other cases the irrigation companies own the most of the lands under their works and sell the lands only with water rights attached. Water rights or rentals are then fixed, and those possessing them are given the privilege of paying so much per annum for the water which they use or which their rights cover. In most cases they are charged for the water whether they use it or not, provided they have purchased a right to it, otherwise the company would lose by inability to sell. In India this is badly regulated, for the agriculturists pay not for the water directly but in land rentals according to the crop raised and the water used in its cultivation. Thus in seasons of abundant rainfall they make no demands for water and for several seasons in succession the Government may derive comparatively small revenues from the sale of water or the rentals attached to the land. Then, when a time of drought occurs, excessive demands are imposed on the irrigation works, rendering it nearly impossible to furnish the supply asked for. It would seem proper that those asking for water or obtaining water rights should be made to pay whether they use them or not.

A few instances of the charges of water companies will better define water rights and rentals and show how these vary. The Colorado Land and Water Company, which takes its supply from the Arkansas river and irrigates land north of La Junta, Colorado, owns alternate sections of the land under their canal. They sell this at from $5 to $10 per acre with a full paid perpetual water right at $800 for 80 acres and in addition charge a water rental not exceeding $16 to cover maintenance and repairs. It will thus be seen that the cost of a water right is about $10 per acre while the water rentals are exceedingly low. The Bear River Canal Company in Utah sell their lands at about $10 per acre with a water right attached and charge $2 per annum per acre for water rental. The Pecos Irrigation and Improvement Company of New Mexico at present sell perpetual water rights for $10 per acre payable in ten annual installments and charge an additional water rental of $1·25 per acre. This company, however, states that the price of their water rights will doubtless be raised in the near future.

On the more valuable fruit lands of California much higher charges are made for water rights than those cited. Land with water is selling generally at from $200 to $500 per acre. In some cases its price reaches even $1,000 per acre. These high figures hold good in such places as the San Bernardino valley and at Riverside, San Diego, and other colonies where the lands are sold in 10-acre tracts with water piped underground to each separate tract. The Hesperis Colony on the upper Mohave river in southern California at present sells land in 10-acre tracts at $100 per acre with a water right. The Merced Reservoir Company of Merced, California, sell 20 acres of fruit land at $150 per acre with a water right attached and charge an additional water rental of $1 per acre or $20 for the tract.

In a majority of cases cited it is seen that the land is sold either with the water, or a water right is sold for the land already owned by settlers, and that the water rentals are charged not according to the amount of water used but according to the number of acres to be irrigated. This is essentially a crude method, as one irrigator may need or use more water than another; one may be extravagant and wasteful of his water, while another is careful and intelligent in handling it. It is to the interest of both the consumer and the company that the water should be sold by measure. This is rarely done, however, in any part of the world, owing to the difficulty attending the measurement of water. A few of the more recent and enlightened companies are now selling water by quantity and making their water contracts accordingly, using every effort to give fair and satisfactory measurement.

The Arizona Canal Company in its water-right deed has some excellent stipulations, the first of which states that there are 1,200 water rights, all of which together are entitled to the use of the first 1,000 cubic feet of water per second which shall flow in the Arizona Canal, and that no water rights have been or will hereafter be created or sold for the use of water to be furnished by the canal to the prejudice of the said 1,200 water rights. The owner of each water right has a vested and indefeasible interest in the canal, ditch, dam, and property of the canal company, and a perpetual right to have and enjoy the privileges conferred upon him in the contract. It is further agreed that the owner of the water right shall pay for the use of the water upon each of the water rights when the water is ordered to be furnished, for the land to which the same are attached, a rental, to be fixed by the canal company:

> At a rate not exceeding 10 cents per hour for each cubic foot per second of flow, until the end of the irrigating year of 1893–'94, and thereafter, shall pay such a rental

as may be established from year to year by the first party thereto, such rental not to exceed 20 cents per hour for each cubic foot per second of flow; provided, however, that where water is brought for a holding of less that 80 acres and not less than 10 acres, a rental may be charged at the rate of 15 cents per hour for each cubic foot per second of flow, until the end of the irrigating year of 1893–'94, and such rental thereafter as may be established from year to year by the first party hereto, such rental not to exceed 25 cents per hour for each cubic foot of flow per second; provided, further, that for subdivisions of less than 10 acres, and for town sites, the rate shall be subject to special agreement.

The water-right deed of the Idaho Mining and Irrigation Company is an improvement on that just cited. Among other provisions it states that the amount of water the company agrees to supply on demand, for and in any one irrigation season, shall be 86,400 cubic feet of water per acre, the same being sufficient water to cover each and every acre of the tract of land nearly 2 feet deep, when no allowance is made for evaporation or absorption. It is agreed and understood that a smaller quantity of water than hereinbefore stated may be taken and used by the irrigator at his option, but that a greater quantity shall not and can not be required of the company under the agreement; it is, however, further agreed that more water may, at the option of the company, be actually furnished the irrigator for which he shall pay at the time and rate specified for payments to be made under the agreement. These rates then further provide as follows:

The irrigator shall pay annually to the company the sum of 10 cents for every acre, whether irrigated or not irrigated, and, in addition, for all water used for irrigation or for domestic purposes the irrigator shall pay annually to the company at the rate of 5 cents for every 1,800 cubic feet of water used. The water to be supplied by the company is to be measured by such devices as the chief engineer of the company shall from time to time prescribe, but the manner shall be such that a person of ordinary intelligence and skill in the measurement of flowing water can at any time ascertain the quantity of water being delivered to the irrigator. It is further provided that on land which has never before been irrigated sufficient water to thoroughly irrigate it shall be delivered to the irrigator at a cost of $2·40 per acre for each acre.

CHAPTER III.

HYDROGRAPHY, EVAPORATION, AND SEEPAGE.

Little attention has been paid in America to the hydrographic questions involved in irrigation construction. The first considerations in devising an irrigation project have been such purely practical ones as the determination of the crops best suited to the soil, the probable yield per acre, the cost of construction of works, and the possible returns. Some grave errors have been made by the failure of the engineers or projectors of irrigation works to determine fully the amount of their water supply, and canals have been constructed the capacities of which were far greater than the volumes of water available.

In order that money may not be wasted in the construction of irrigation works several factors dependent upon the water supply should be first determined. This can at once be done only provisionally. Observations maintained through a number of years are necessary in order that these factors may be determined with any degree of accuracy. Private companies can not afford the time necessary to accomplish this. To ascertain the rainfall for average years, as well as the maximum and minimum rainfall, the percentage of run-off from the catchment basins and the discharge of the streams by means of gaugings, requires a prolonged series of observations conducted through a period of years. Experiments to determine the evaporation, the seepage, and the amount of sediment carried in suspension likewise require time before useful results can be obtained. Within the past few years good work has been done to this end by the hydrographers of the Geological Survey, as well as by some of the state experiment stations. The state engineers of California, Colorado, and Wyoming have gauged several of the more important streams in their states, and from these we are able to obtain some useful data.

By far the most important work done in this direction is that performed by the hydrographers of this Survey under Mr. F. H. Newell, who has fully reported the detailed results of these observations in the Eleventh and Twelfth Annual Reports and in another part of this volume. There remains, however, very much to be done, and while it has been necessary to discontinue the work of the Geological Survey, so good an example has been set to the public that state colleges in the West are now continuing this work, and in the near future we may hope for a larger volume of results than are now accessible.

As before stated, it is very desirable to have approximate values of the percentage of run-off of the various catchment basins in order that, in connection with the rainfall shown by the observations of the Weather Bureau, approximate estimates may be made of discharges of streams. As a result of inquiries made by engineers of this Survey in 1889 and 1890 it was discovered that in eastern Nevada at the head waters of the Truckee river the average depth of run-off was 19 inches, while the run-off at the heads of the minor forks of this river in the higher Sierras averaged about 50 inches. This is equivalent for the whole of the Truckee river basin to a run-off of about 45 per cent of the precipitation, and on the higher branches, where the slopes are steeper and the surface more rocky to a run-off of about 65 per cent. Similarly at the head waters of the Carson and Walker rivers the run-off on the mountain catchment basins averages in all 65 per cent of the total precipitation. In Colorado, on the upper Arkansas river drainage basin, similar results were obtained, the depth of run-off averaging about 20 inches, or 66 per cent, where the total amount of precipitation averages 30. On the flatter slopes of the plains the percentage of run-off is much lower—from 30 to 10 per cent, or even less. Experiments to determine the amount of losses by evaporation and seepage have given us some results on which to base calculations, but these are very meager. Further experiments must be conducted either by private parties, agricultural experiment stations, or the Federal government.

The volume lost by evaporation varies greatly, according to the locality. In the higher latitudes of the arid regions, as Montana, the annual depth of evaporation varies between 32 inches in the northern portions of the state, near Great Falls, to 36 inches in the lower and warmer regions along the Yellowstone and in the Gallatin valley. In Colorado the evaporation varies with the altitude, being in the loftier portions of the Rocky mountains in some places as low as 36 inches, or about 3 feet, and rising to 4½ or 5 feet on the lower plains in eastern Colorado. In Arizona and New Mexico the evaporation is proportionately greater, reaching from 5 to 6½ feet, and at El Paso, where prolonged records have been kept, it is as high as 7 feet. The State Agricultural College of Colorado is doing some good work in the way of making observations for evaporation. Experimental tanks have been placed in the college grounds and in the San Luis valley and if the observations are maintained for a period of years we shall doubtless receive some trustworthy data for these localities.

The subject of the losses by absorption (by which is meant evaporation and seepage) and our present knowledge of these, so far as it can be gained from European and Indian practice, was discussed in the Twelfth Annual Report of this Survey in my paper on Irrigation in India. In our own country we have a very fair knowledge of the quantity of water lost by absorption, obtained from experiment and measurement on some of the older canals. It may be laid down as a rule that the losses from absorption are much greater in new canals than in old ones. At first, if the soil is sandy, a canal will permit of considerable losses; it will be safe in nearly every case to estimate these in long lines of new canals at from 40 to 50 per cent of the volume entering the head. If the length of the canal is smaller, the percentage of loss will be decreased. In very long lines of new canals and in unfavorable soil the losses from absorption may reach as high as 60 per cent, while they will rarely be as low as 30 per cent. As the canal increases in age the fine silt carried in suspension and deposited on its bank and bottom, fills up the interstices and rapidly diminishes the losses from seepage. Mr. Walter Graves, of Colorado, puts the loss in old canals as low as 12 per cent. This is doubtless too low for most instances; it will apply only to short canals where the water is utilized the moment it leaves the head gates. In general, for canals of average length, the loss by absorption will be reduced to 20 per cent inside of a few years, though in the case of particularly long canals it will rarely fall below 25 per cent. In the Ganges canal in India the losses by absorption after the canal had been in use for some years were as high as 70 per cent. This canal, however, is several hundred miles in length, while the total length of the main line and larger branches and distributaries is about 4,000 miles.

One of the most glaring errors in construction in the west is that of utilizing depressions along the line of a canal as part of its channel. Thus where minor side streams are passed only the lower bank is built up and the water allowed to spread out in a lake or pond on the upper side of the canal bank, the natural slope of the hill being used as the upper bank. In these places the losses by absorption are greatly increased and the capacity of the canal correspondingly reduced. This plan has been resorted to in order to save cost in construction, and while it is always of doubtful propriety at the beginning, it should certainly be remedied as fast as the resources of the company will permit. Loss by absorption is chiefly due to the faulty construction of minor laterals and distributing ditches. These are usually built by the farmers themselves and are badly aligned and located. A little intelligent supervision of these works on the part of engineers would soon educate farmers to the proper method of building minor channels.

Canals frequently receive large supplies of subsurface water from the seepage of other canals and the natural ground water in the soil. This seepage often largely replenishes the losses from the canal itself. It is a well-established fact in the arid region that before irrigation becomes universal in any locality the water in the streams is greatly decreased in volume after it leaves the mountains. This is due in such places as the eastern Colorado plains to the natural loss by absorption as the streams approach the plains, while they receive no replenishment from the surrounding country.

Observation and experience show that seepage water is an important factor, adding largely to the volume flowing in the lower courses of some streams. Carefully conducted experiments and measurements to prove this were instituted in Colorado in 1885 by Mr. E. S. Nettleton, state engineer, and were continued by him as opportunity offered for several years. Some interesting data were secured as a result.[1] On the Cache La Poudre river, starting with a discharge of 127·6 second-feet in the canyon before any water was diverted by the canals, the volume at a point considerably lower down on the stream near the town of Greeley, had increased to 214·5 second-feet after supplying 15 canals; showing the addition of more than two-thirds of the original volume to supply canals further down the valley. Other experiments, conducted by Mr. Nettleton in 1889 while superintending engineer of this Survey, indicated that as much as 80 per cent of the water used in irrigation was returned to the river lower down after it had performed its duty in irrigating the lands.

As early as 1874 the withdrawal of large quantities of water from navigable rivers for purposes of irrigation caused some alarm in California, as it was feared that it might result in diminishing the depth of water in the Sacramento and San Joaquin rivers. A board of commissioners, consisting of Col. B. S. Alexander and Maj. George S. Mendel, of the Engineer Corps of the U. S. Army, and Prof. George Davidson, of the Coast Survey, was appointed by the President to examine into the possible effects of irrigation on the navigation of these rivers.[2] These officers discovered that the amount of water finding its way back to the rivers by means of seepage after it has been used in irrigating the lands was so great that at a comparatively few miles below the head-gates of the canals large volumes of water may be expected to appear again in the stream.

DUTY OF WATER.

The duty of water is the ratio between a given quantity of water and the amount of land it will irrigate. It may be variously expressed as the number of acres of land which one second-foot of water[3] will irrigate, or as the number of acre-feet of water[4] required to irrigate an acre of land, or as the total volume of water used during the season. Another form of expression, which is not in common use in this country, but which may be satisfactorily employed when the location of the canal line has been determined, is to state the expenditure of water per linear mile of canal. In India this quantity has been found to vary from 6 to 8 cubic feet per mile. In considering water duty, the fact, however, must never be lost sight of that this differs greatly, according as it is reckoned on the quantity entering the head gates of the canal or on the quantity applied to the land, since the losses by seepage, evaporation, etc., in transporting the water to the land are very considerable.

---

[1] Third Biennial Report, state engineer of Colorado, E. S. Nettleton, Denver, Colorado, 1885.

[2] Report of Board of Commissioners on Irrigation, House Mis. Doc. No. 290, Forty-third Congress, first session. Government Printing Office, Washington, D. C. 1874.

[3] A second-foot of water is one cubic foot of water flowing past a given point in one second of time.

[4] An acre-foot of water is the amount which will cover one acre to a depth of one foot or 43,560 cubic feet.

It will always be impossible to accurately fix a correct standard for the duty of water, as this quantity varies with different soils and crops and with different climates, altitudes, and modes of applying it to the crops. It must, however, be approximately determined for each case before the science of irrigation engineering can reach the high plane attained by other branches of the profession. At present the solution of this problem is somewhat remote. Carefully conducted experiments must be made in various localities, and with the various crops there grown before even an approximate degree of accuracy can be attained. Such a work, for obvious reasons, should properly be conducted by the general government, and is now being indirectly so conducted through several of the agricultural experiment stations in the arid region. The experiment station in Colorado, under the direction of Prof. L. G. Carpenter, that of Arizona, under the direction of Prof. F. A. Gulley, and that of Utah, under Prof. John W. Sanborn, are all doing good work in this direction.

The duty of water as at present accepted in the various portions of the West is a matter of extreme variability and doubt. What the duty of water actually is is being constantly disputed and changed by various engineers in their reports and writings on the subject and in testimony given before courts. Only during the last ten years has the handling of water for irrigation purposes fallen to the lot of intelligent engineers and experimentalists, and in that time the duty of water in Colorado has nearly doubled, while it has more than quadrupled in portions of California. It is now generally recognized that the duty of water will for some time yet continue to rise as better modes of handling it are devised and as the amount required by certain soils comes to be understood through experience and practice.

In 1883 Mr. E. S. Nettleton, state engineer of Colorado, estimated the duty of water in Colorado to range from 50 to 55 acres per second-foot, while the average pioneer irrigator of the time used as his standard "an inch to the acre,"[1] which would equal about 38·4 acres per second-foot. As late as 1886 Mr. George G. Anderson, in writing on the subject, gave the same figures as Mr. Nettleton. About this time examination was made of the practice of irrigation among the most successful farmers, and from the best illustrations among them a standard water right of 80 acres per second-foot was determined as being a fair average. Some early experiments made by Mr. O'Mera in the Cache La Poudre valley showed that of two classes of soils selected, one clayey and retentive, the other light and porous, the former required 33 per cent of water for saturation in an unbroken state and 40 per cent after being broken, and the latter required 38 per cent when unbroken and 44 per cent when broken.

---

[1] Meaning a miner's inch to an acre.

As land is irrigated through a series of years and finally becomes saturated, the subsurface water-plane rises, and as it approaches the surface the amount of water necessary for the production of a crop is diminished. It has been likewise discovered that the tilling of the soil during a period of years renders it more capable of producing crops, and consequently diminishes the amount of water required for their cultivation. From these causes and those already mentioned, engineers in Colorado, as well as elsewhere in the West, have in the last few years been increasing their estimates of the duty of water. State Engineer Maxwell and others have recently estimated the duty of water in Colorado as high as 100 acres, and some of these gentlemen are already endeavoring to induce capitalists to accept 125 acres as a fair duty. In Utah and elsewhere much the same development has occurred. Mr. Charles L. Stevenson, who in former years estimated the duty of water at 60 acres per second-foot, has as recently as 1887 stated that the duty in Utah is 100 acres. According to the census bulletins prepared by Mr. F. H. Newell, the average duty of water flowing from wells in the territory of Utah has been ascertained to be 80·3 acres per second-foot. There is little doubt, however, that the duty of water in Utah averages about 100 acres.

In a paper read before the American Society of Civil Engineers,[1] Mr. Edward Bates Dorsey showed that in the eastern portion of the United States the rainfall is about 4 inches per month, and estimating the crop-growing season at one hundred days, or roughly four months, the depth of rainfall necessary for a crop is about 16 inches. This amount of water would give a duty of about 180 acres for each second-foot. In careful estimates made by me, while the Government irrigation engineer for Montana, it was discovered that about 1¼ acre-feet to the acre was the duty for that state, or about 16 inches in depth. For flowing water the duty was estimated to be about 100 second-feet.

In the state of California water duty varies greatly according to the locality and the mode of applying the water. In Riverside, where water is taken to the land in wooden flumes and permitted to run over it from holes in their sides, the duty for surface irrigation is quite high. It was estimated by Mr. James D. Schuyler in 1880 to be 300 acres per second-foot. In open ditch irrigation in San Bernardino valley, the same engineer concluded from various experiments that the duty of water was 133 acres per second-foot. In the upper San Joaquin valley in California the assumed duty of water has remained for the past ten years for cereals at about 150 acres per second-foot for shallow clayey soils; for deep and light loamy soils the duty at first is rarely over 50 acres, but has gradually risen to about 100 acres.

According to testimony before the special Senate committee on irrigation in 1889, it was estimated by the engineer at Ontario, in San Bernardino county, that the duty of water when applied by subirrigation from pipes varied from about 250 to 500 acres to the second-foot. The same results were given for subirrigation in Riverside. Where carefully practiced, however, in some special cases a duty as high as 1,000 acres has been obtained by subirrigation from pipes. Such results have been obtained only in orchards where a separate outlet pipe is laid to each tree.

---

[1] Irrigation, Edward Bates Dorsey, Trans. American Society of Civil Engineers, vol. XVI, March, 1887.

Mr. Elwood Mead, state engineer of Wyoming,[1] made some experiments for the Wyoming Development Company, near Cheyenne, using the water from a small ditch in the irrigation of 123·7 acres of oats and on a small patch of potatoes. From these experiments he established a fact, which was already generally accepted, that wild land requires more water for irrigation than land which has been cultivated for several years. The average discharge on the oat field was 3·8 second-feet, equivalent to an average discharge for the four months' irrigating season of 1·32 second-feet, or an equivalent duty of 93·8 acres per second foot. The potatoes required an average discharge for the four months' irrigating season of ·03 of a second-foot, or an equivalent duty of 229·5 acres per second-foot. The amount of water used on the oats would have been sufficient to cover the entire surface to a depth of 2·6 feet, and that used on the potatoes was equal to a depth of 1.06 feet over the entire surface.

On the Cache La Poudre canal a record was kept[2] of the depth of water entering the canal and that used, and from these records Prof. Carpenter found that the discharge was sufficient to cover the whole area irrigated 21 inches in depth. The average duty, including rain, was computed to be 120 acres per second-foot, though this water was used almost exclusively on cereals and alfalfa. Mr. Carpenter sums up by stating that "the average duty is misleading, and during the period when water is wanted in the greatest quantities the duty ordinarily taken in Colorado, 55 acres per second-foot, is the safer guide." There is little doubt that this is an overconservative conclusion, for recent results obtained by all the more experienced irrigators show the duty to be over 80 acres per second-foot when the water is properly handled.

ALIGNMENT, CROSS SECTION, AND SLOPE.

American engineers will never adopt the expensive methods of marking out location and construction lines that are employed by foreign engineers. In Europe, and still more conspicuously in India, each canal alignment is indicated by magnificent stone monuments set every 100 feet along the line and by expensive bench marks of masonry built at frequent intervals.

---

[1] Second annual report, territorial engineer of Wyoming, for year 1889, Cheyenne, Wyo., 1890.

[2] State Agricultural College of Colorado, Third Annual Report, Agricultural Experiment Station, Fort Collins, Colo., 1890.

I believe that the most desirable way, and, in the end, the cheapest way, to make a canal location is first to construct a contour topographic map of the entire area to be commanded. On this map the main and lateral lines of the canal can be located and the engineer can take this location and stake it off on the ground with such slight alterations as may seem necessary. Perhaps the best example of work of this kind is the alignment of the Turlock canal in California. Mr. E. A. Barton, the chief engineer, has constructed a topographic map on a scale of one thousand feet to the inch and in 5-foot contours of the entire Turlock irrigation district, which contains over 76,000 acres. On this map he was able to lay out not only his main canal, but all of his laterals and distributaries, and got at once what was unquestionably the best locations that could have been chosen for the work.

To choose the correct slopes requires much skill and consideration, and a wide diversity of opinion exists among engineers as to the best form of cross section, and as a natural result many differences exist between the canals of the country in this respect. Some are given even slopes of from 1 on 1½ to 1 on 4, according to the soil. The canal is kept as far as possible in excavation, and the waste material is deposited carelessly on either side. Others endeavor to balance the excavation and embankment, building up the latter with great care. In these cases the inside slopes are sometimes uniform, at other times they are broken by a berm left on the natural surface of the soil at a point where the artificial bank and the excavation meet. The width of this berm differs, as does the top width of the made bank. Others again, even where it is necessary to construct a canal almost wholly in excavation, have the slopes in some cases smooth, in others broken by a berm in the made bank. As most canals in following the contour of the country are built on hillsides or on sloping ground, it is rarely necessary to build embankments on both sides. All material is moved to the lower side and formed into a heavy bank, while on very steep ground retaining walls of various forms are employed.

It is now considered best, especially in light soils, to adopt a cross section having a subgrade of from 1 to 2 feet, with the bottom sloping toward the center. This cross section gives a wetted perimeter as near the form of an ellipse as possible, for this form presents the least surface to friction or opposition to the flow of water in open channels. While experience has shown that the subgrade tends to keep the current in the center of the channel and to maintain a flow of water with the least exposure to friction and seepage when the volume in the canal is low, the adoption of a berm is equally advantageous. Large canals are rarely called upon to carry a full capacity for several years after construction, and until such time the water can be confined to the excavated portion of the channel and thus give the outer bank time to settle.

In the sandy soils of the San Luis valley in Colorado and in the upper

San Joaquin valley in California slopes of from 1 on 2½ to 3 have been found most desirable, while the top of the made bank has been given no definite width, but has been allowed to assume the natural slope of the soil. The result has been to produce a gentle curve, as shown in Fig. 66, A. On the Arizona canal a similar form of construction has been employed, the berm being dispensed with, though in this case the made bank is about 10 feet in width on top. In firmer soil, such as rich loams or slightly clayey loams and gravels, slopes of 1 on 1½ to 2 are sufficiently permanent, and in such cases the berm can be advantageously introduced. On the Idaho Mining Company's canal in gravel and coarse sand the slopes given (Fig. 66, B) average about 1 on 1½, with a built up bank 8 feet in width and no berm or subgrade. On the Bear river canal in such firm material as disintegrated shale or slate and coarse gravel, slopes of 1 on 1 were found to stand satisfactorily and were made without berm or subgrade. On the Turlock canal in the peculiar gold-bearing gravels of California, which frequently approach in hardness the quality of hard-pan, one cut 80 feet in depth was given slopes of 1 on 1 (Fig. 66, C), while equally steep slopes were given in less deep cuts in other places. In rock the slopes may vary from 4 to 1 on 1, according to the firmness of the rock, 2 on 1 being about proper for ordinary friable sandstone or slate.

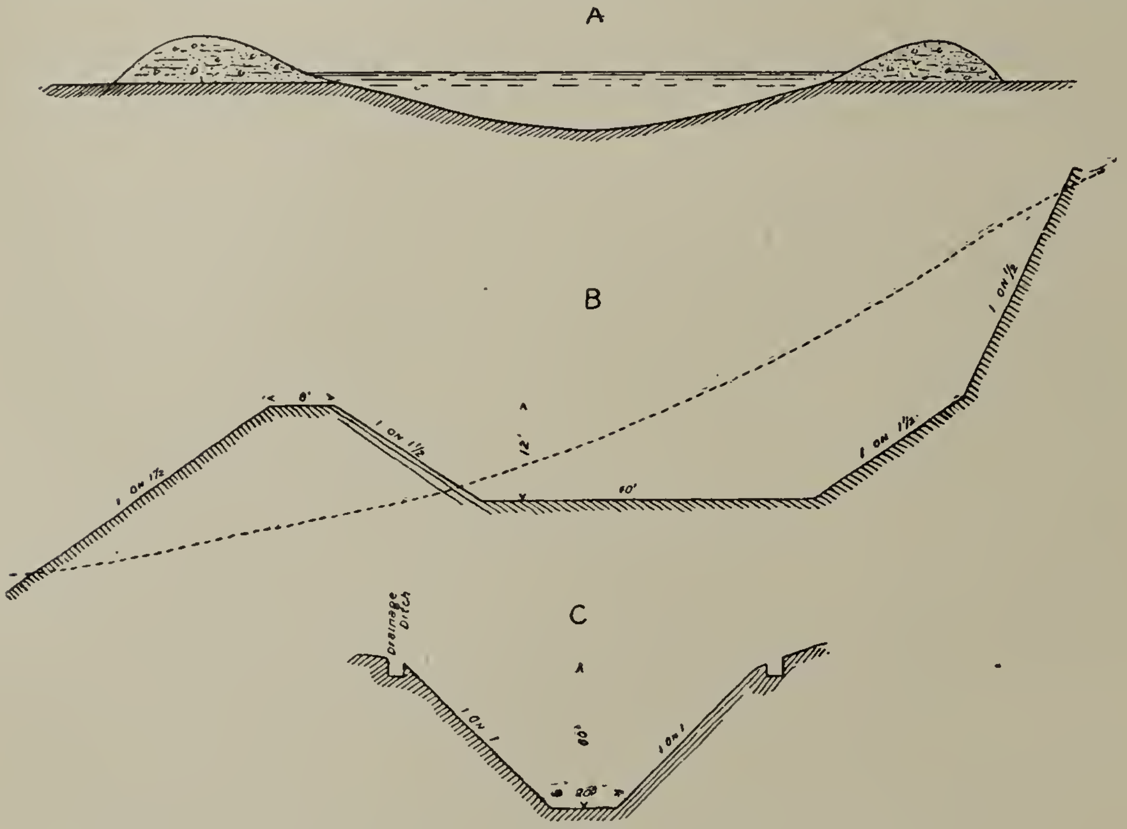


FIG. 66.—Cross sections of canal banks Calloway (A), Idaho (B), and Turlock canals (C).

There is the widest difference of opinion as to the proper grade and consequent velocity to be given in different soils. In the older canals in Colorado the grades established were too high, seldom less than from 3 to 5 feet per mile. In later constructions lighter inclinations have been adopted, ranging from 6 inches to a few feet per mile, according to the cross section of the canal and the material. In the sandy valleys of southern Colorado, Mr. Walter Graves has adopted very light grades. For canals from 30 to 50 feet wide at the bottom he gave slopes ranging from 1 in 6600 to 1 in 1760. On the Citizens' canal, in San Luis valley, the fall along certain portions of the line is 1 in 10,560, or 6 inches to the mile.

In rock, hard-pan, and firm gravel a velocity of 5 to 7 feet a second is generally given, as the cross section of the canal can thereby be reduced. In firm clayey loams as high as 4 feet per second is sometimes given. In ordinary soil and firm sandy loam 3 to 3½ feet per second is considered a safe velocity. Probably the highest grade ever given to any canal is that on the Del Norte canal in Colorado, which has a fall of 35 feet per mile in a rock cut. (Pl. CXII.) The object here was to create a fall so as to lose grade. On a large portion of this canal the grade averages 8 feet per mile until it reaches the earth soil in the valley, where it is reduced to 1 in 2112. On the Highline canal in Colorado are 4 miles of earth excavation, in which the total fall is 208 feet, followed immediately by a flume 612 feet long, in which the fall is 28 feet. The line, however, is straight at this point, and by the aid of wooden checks or falls the erosive force of the water has been largely counteracted, though considerable damage was done to the channel.

CHAPTER IV.

CLASSES OF WORKS.

Of the irrigation practiced in this country almost all—probably ninety-nine one-hundredths—is by means of gravity. That is, the water is conducted by natural flow to the ground to be irrigated. The percentage of lift irrigation is as yet so small as to be inappreciable.

Lift irrigation is practiced wholly from wells and may be divided into five principal classes, viz: (1) Pumping by steam power. (2) Pumping by windmills. (3) Pumping by water wheels. (4) Pumping by animal power. (5) Lifting by elevators.

Each of these will be further discussed in its place.

Gravity irrigation includes five great classes of works, viz: (1) Perennial works. (2) Periodical works. (3) Storage works. (4) Irrigation from artesian wells. (5) Irrigation from subsurface sources.

Under the head of perennial works are included all those canals which receive their supply from streams, the discharge of which suffices at all times for the irrigation of the lands commanded by them. Periodical works include those canals which are taken from streams having an available supply during a portion of the irrigating season only. They are usually very small in size and are mostly used in climates or latitudes where the natural moisture of the soil is sufficient for the cultivation of crops, when the latter can be started by means of one or two waterings in early spring, obtained from early spring rains or melting snows. Storage works are constructed on intermittent streams the flood waters of which must be stored in order to furnish a sufficient supply during the irrigating season, or else they are constructed on some interfluve with the object of utilizing the surplus or flood waters from some main stream which is led to them by a canal. Irrigation from artesian wells is practised wholly by means of canals taking the waters directly to the lands from the wells or from some small reservoir in which the well water is stored. Irrigation from ground water sources is by tunnels under stream beds or into the hillsides to tap some water-bearing stratum, or by open cuts in sloping ground, or by wells to collect the ground water.

Climate, geology, and topography are the chief factors in deciding on the class of irrigation work which essentially belongs to a given region. Where precipitation is very small, occurring usually during a short period of the year, storage works must be resorted to. This is the case particularly in Arizona, southern California, and Nevada, where streams discharge large volumes of water in the early spring months, but dwindle to mere rills or entirely dry up in summer. In streams flowing from the Sierras in California and from the high mountains in Colorado, Montana, and Wyoming the perennial discharge is generally sufficient for most purposes of irrigation. This is because of the slow melting of snow on the higher mountain peaks, the water from which keeps up the stream discharge long after the rains have ceased.

Periodical works are practicable chiefly in the intermountain valleys of Montana, Colorado, and Wyoming, where small streams furnish a sufficient discharge in early spring for irrigating young crops, and after they run dry occasional late spring showers suffice to mature the crops. It is not only in such dry regions as southern California and Arizona, however, that storage works are valued. The larger perennial streams of Colorado, Nevada, and Utah and the remainder of the arid West can have their irrigating capacity greatly increased by the construction of storage works, and as the perennial flow of these is appropriated and utilized, similar works must be constructed for the conservation of flood waters. The topography greatly affects the classes of works, for although climatic and hydrographic conditions may be favorable to their construction, the topography of the country may be such as to entirely preclude it, owing to the impossibility of finding suitable reservoir sites.

Artesian wells exist in large numbers only in a few localities, while they are distributed very generally throughout the arid region. They are most abundant in the Dakotas, Texas, Colorado, and southern California. A few are of great size, and discharge sufficient water to irrigate small farms, but most of them discharge relatively small volumes, and are of little use as sources of supply for irrigation, though furnishing an abundance of water for domestic use.

PERENNIAL CANALS.

As yet no great perennial canals have been constructed or even designed in the United States, that is, none which in size and importance are comparable with those of India. Several canals of considerable magnitude have been built, exceeding both in length and capacity any in the rest of the world, excepting only those of India and one in Italy. Among these, in the order of magnitude and importance, are the Turlock canal, diverted from the Tuolumne river, in California; the Idaho Mining and Irrigation Company's canal, diverted from the Boise river, in Idaho; the Pecos canal from the Pecos river, in New Mexico; the Bear River canal from the Bear river, in Utah, and the Highline, Calloway, Wyoming Development, and numerous other lesser canals in different parts of the West.

Projects have already been suggested and have received some slight consideration for the utilization of the waters of the Yellowstone river in Montana, the Colorado river in southern California and Arizona, the Columbia river in Washington, the Missouri river in North Dakota, and the Sacramento river in northern California. It will, however, probably be many years yet before it becomes necessary to construct any of these great works; that they will ultimately be built there is no doubt. The canal of the Central Irrigation District in Colusa county, California, which has already been constructed, takes its water directly from the Sacramento river by means of an open cut, with no weir or dam below its entrance. A dam at or near this point would provide a perennial discharge for a canal of several thousand second-feet capacity. The Yellowstone river would readily furnish at least 3,000 second-feet and with the aid of storage in Yellowstone lake it would supply double that volume.

The machinery of a great perennial canal consists essentially of the following parts which are treated in this report in the order here given: (1) Source of supply. (2) Lands and crops. (3) Main canal. (4) Headworks. (5) Regulating and drainage works. (6) Distributaries and laterals.

The two principal units of this system are the main canals and the distributaries, each of which has its own set of regulating works and escapes to control the supply of water. Between different canals these differ slightly in general principle but vary greatly in detail. The points of greatest difference are usually found in the headworks and in the first few miles of diversion line, where various difficulties have been encountered in bringing the water to the irrigable lands and in the passage of hillside drainage.

KINGS RIVER CANALS.

Of the works of any magnitude in California, among the first were the Fresno, the Kings river and San Joaquin, the Musselslough, and a few other canals built in the San Joaquin valley. Kings river, from which these various canals are diverted, has a drainage area of about 1,855 square miles in the Sierra Nevada mountains, nearly half of which is situated well within the snow belt. After its exit from the foothills it flows for a distance of about 62 miles to Tulare lake, into which it empties. In its passage through the bottom or plains land between the foothills and Fresno, its waters are divided into several channels for a distance of about 15 miles, after which it is all again collected and confined to a single deep channel, the bed of which is from 20 to 60 feet below the plains on either side. From its exit at the foothills to the lower end of the Centerville bottoms the grade of the river varies from 12 to 17 feet per mile.

Kings river has two floods in each year. The first occurs usually in December after the rains have set in, and the second commences about the first of May. The time of greatest demand for water for irrigation is during the winter and spring floods when the river is capable of supplying nearly all of the water required. The maximum discharge averages about 9,000 second-feet while the minimum discharge is frequently as low as 210 second-feet, the mean discharge being about 1,700 second-feet. The highest maximum recorded discharge occurred in the flood of 1861, and was considerably greater than the average maximum discharge.

The Kings river and San Joaquin canal diverts the water from the north bank of the river and conducts it to the highlands above Fresno; with its branches it is about 22 miles in length. The Fresno, or, as it is more commonly called, the Church canal, is diverted from the river at a point about a mile below the head of the Kings river canal, and irrigates the lands in the immediate neighborhood of Fresno city, south of which it passes. This canal for considerable of its length occupies a natural channel, known in its upper portion as Mud creek and further down as Fanshaw creek. With its main branches it is about 63 miles long. The Kings bridge and Centerville is the third of the large canals diverted from the north bank of the Kings river; its total tength is about 26 miles. From the south side of the river are diverted six principal canals which head below the crossing of the San Joaquin valley railroad. These are the Peoples, Last Chance, Lower Kings river, Musselslough, Rhodes, and Southerland Slough ditches. Their total length is 116 miles.[1]

The canals of this region are rudely constructed and are wasteful of water and expensive to maintain. In the Musselslough country in particular the works have been located and constructed with the least skill. Several of the canals have grades so low that the velocity of the current is not sufficient to prevent the rapid growth of aquatic plants. While in some places the slopes are too light, in others they are so great as to cause serious damage by scouring and erosion. There are about 4 miles of each of the five main canals in the Musselslough district, making in all about 20 miles of the most expensive portions of these canals with their head gates and dams, which are used for diversion only. Sixteen of these 20 miles could have been avoided had a proper plan for the irrigation of this district been decided upon in the beginning, involving the construction of one large canal from which the others could have been diverted as branches.

The Fresno canal was constructed in 1872 by Mr. Isaac Friedlander, under the direction of Alfred Poett, civil engineer.[2] This canal is diverted from the Fresno river by means of a timber dam 311 feet long, which raises the water 6 feet above its original level. It is constructed of two rows of main piles, from 20 to 35 feet long, planted 10 feet apart and driven firmly into a stratum of clay. Between the piles is a double row of 4-foot sheet piling, and the space between the two rows of piles was filled in solid and planked on top. Below the toe of the dam is a timber apron of 4-inch plank set at an incline, and from this the water passes on to a thick layer of loose rock. The headworks of the canal consist of a sort of flume of timber 30 feet wide and closed by six gates, The canal has a uniform bed width of 20 feet with side slopes of 1 on 2. the depth of the canal being 8 feet and the depth of water 6 feet. Where they are in embankment the top width of the canal banks is 4½ feet. The canal has been enlarged in recent years until it now has a bed width of 50 feet while its grade has been increased along its main line to 8 feet per mile, chiefly in hardpan, and hence not liable to erosion. The depth of water is 5 feet and its capacity 1,500 second-feet. These dimensions are maintained for the first 20 miles, after which they diminish, owing to the diversion of branches. Of these one of the larger is known as the Enterprise canal, which is diverted from the main Fresno canal 1½ miles from its head. It is probable, however, that in a short time this branch will derive its entire supply from the Fresno canal. The bed width of the Enterprise canal is 16 feet, grade 2 feet per mile, velocity 2·2 feet per second; slopes of its banks, 1 on 1½. These banks are 3 feet in height above the bottom of the ditch, its capacity is 80 second-feet, with a depth of 2 feet of water.

---

[1] Report of the State Engineer of California, P. IV, Appendix, J. D. Schuyler, Sacramento, 1880.

[2] Irrigation in California. Sacramento, California, 1873.

Generally the heads of the distributaries diverted from the main or branch canals consist of an arrangement of fluming and boxing closed by simple sliding gates. The main distributing ditches are usually 10 feet wide at the bottom; slopes 1 on 2; top width of banks, 2 feet; height above grade, 2 feet, with varying grades, the maximum rate being 33 inches to the mile and the velocity averaging about 2¼ feet per second. In designing the Fresno canal it was estimated that it would irrigate 72,000 acres at a duty of from 200 to 400 acres per second-foot.

It is an interesting and notable fact that whereas the duty of these earlier canals in California did not at first rise much above 80 to 100 acres, experience in the use of water and its increased value are daily causing this duty to increase, so that now it not only reaches the earlier estimates, but in some cases even passes them. Another of the weak points in earlier construction was the steep grades and high velocities given, and practice is now bringing these down to the theoretical dimensions designed for the Fresno canal. The earlier canal works of California were faulty in many respects, but chiefly in the location and construction of their headworks. These were built in an unsubstantial and cheap manner, causing great loss both in the operation of the canal and in the necessarily frequent reconstruction of the weir. In all cases the alignment was faulty; sometimes sharp bends were made, which greatly retarded the flow of the water and caused the deposit of sediment and erosion of the banks, while other constructors went to the opposite extreme, giving great broad curves such as would be necessary on a railway line. No provision for the discharge of flood drainage was made, and the canals were frequently destroyed, owing to their gathering local flood waters for which no relief was provided, while grades were equally faulty, the chief error being in making them too steep. The Fresno canal as originally constructed cost only $60,000. The later improvements and enlargements have necessarily added considerably to this figure. The water in the Fresno canal is valued at about $1,000 per second-foot, and is divided into 1,500 water rights of $1,000 each. These are calculated to irrigate 160 acres each.

The most extensive and one of the most important of the Fresno county canals is the Kings river and San Joaquin canal. This canal is diverted from the San Joaquin river near the mouth of Fresno slough, where an island divides the slough into two unequal portions, the westernmost being the smaller, and across this channel the diverting weir is constructed. A brush dam is thrown across the main channel on the east side of the island in order to maintain a full volume of water in the lesser channel. In 1871 this canal was constructed for 38½ miles; it has been since extended until its length is over 67 miles. The older section of the canal had a bottom width of 28 feet and depth of 4 feet, with side slopes of 1 on 2. In 1873 the canal was reconstructed and deepened throughout to 5½ feet, with slopes sufficient to make its surface width 68 feet. Its grade is 1 foot per mile. The weir at the head of the canal consists of two rows of sheet piling, the space between which is filled with gravel and planked over. Upon this main foundation is erected a frame carrying the sluice gates and head works. These consist of a regulating bridge with 40 feet of clear opening and a weir or sluiceway 55 feet in width between the head of the canal and the island, and the brush dam before spoken of which is about 350 feet in length.

The regulating bridge is a wooden structure founded on piles driven 30 to 40 feet into the quicksand, and the sluiceway on the west side of the island is arranged to permit the passage of steamers during the season when the river is navigable. In low river, when the supply is insufficient to fill the canal by the ordinary flow of the current, the gates in the sluiceway are raised, thus increasing the elevation of the water surface. These gates, which are hinged at the bottom to the floor of the sluice, lie flat upon the floor during high water, and when raised are held in position by a hoop and rod on the upstream side. The maintenance of the headworks has been difficult and costly, owing to the frequent destruction of the brush dam by high water. The dimensions of the canal are now 32 feet bottom width, side slopes 1 on 3, and height of banks 6 feet. These rise 2 feet above the surface of the water. This canal was constructed by Mr. N. Hangroon, civil engineer, though several alterations were afterwards made by J. M. Brereton. The distributing system consists of a number of primary canals, each comparatively short in length, averaging about 12 feet bottom width and 2 feet in depth. Below the twentieth mile are 18 canals from 8 to 18 feet bottom width. Beyond the fortieth mile are four canals 8 to 10 feet in width at the bottom, and from this on to the sixty-seventh mile, the terminus of the canal at Orestimba creek, are 22 short canals of from 8 to 10 feet in width. The total length of these distributing canals aggregates 120 miles, in addition to which are a number of minor ditches constructed by private individuals.

At intervals of from 3 to 5 miles along the line of the canal are placed regulating gates, the object of which is to divert the water into the branch canals. In the first thirty-nine miles are six of these structures, five of which are combined with drawbridges to permit the passage of canal boats, and two are connected with escape sluices. It has been found recently, however, that irrigation and navigation were incompatible without a system of locks, and a new and simpler form of regulating gate and bridge has been substituted for the old drawbridges. The character of the soil along this canal is an alkaline adobe, which crumbles when dry and is subject to the erosion of the water. Willows have been planted along the margin of the canal and the slopes sodded with salt grass to diminish the destructive action of the current. This action has been most disastrous on the outer line of the curves, showing that the wash is due more to the sharpness of the curves and the velocity of the current than to the effect of the winds which blow incessantly across the valley. The plan recently adopted in maintaining the canal is to add material on the outside of the banks where they are weakened by erosion, allowing the soil to assume whatever slope it may naturally take under the action of the water. Owing to the lack of water it has been found that the discharge of the canal rarely exceeds 600 second-feet, or about 80 per cent of its actual capacity.

CALLOWAY CANAL.

This canal, which is diverted from the north bank of the Kern river a short distance above the town of Bakersfield in the upper San Joaquin valley, was located in 1875, and, while it appropriates 1,476 second-feet of water, its capacity is little over half this amount. The lands of Kern valley, which are irrigated by the Calloway canal, are among the richest in the fertile state of California. The surface of this land is peculiarly well adapted to the construction of ditches and the processes of irrigation, as its slopes are even and it has an easy, uniform grade.

Kern river, the waters of which are utilized for the irrigation of this region, rises in the Sierras. It flows 95 miles in a westerly direction through the mountains, after leaving which it flows for 18 miles between high, gravelly banks. Near the town of Bakersfield it is divided into numerous channels, forming a delta. Some of these channels empty into Kern and Buena Vista lakes to the south, while others discharge westerly and northwesterly into Buena Vista slough, the upper drainage being through old river or Buena Vista slough to Tulare lake and the San Joaquin river. Kern river has a catchment area of about 2,345 square miles. From the years 1878 to 1884, inclusive, gauging observations were made on this stream by the state engineer of California. From these it appears that its mean annual discharge varies between 500 and 2,400 second-feet. Its maximum recorded discharge is 12,000 second-feet, though in 1867 it reached a flood discharge of about 30,000 second-feet. During the irrigating months, from February to July, inclusive, its discharge rarely falls below 500 second-feet, and averages about 1,500 second-feet.

Kern valley is composed in places of a rich, sandy loam, though most of the soil, especially that under the upper portion of the Calloway canal, is very light and consists almost wholly of sand. The effect of years of irrigation on this soil, however, has been to produce a marked increase in its fertility and a change for the better in its composition. The sediment which has been deposited upon it from irrigation waters has filled up the interstices between the particles of sand and aided in fertilizing it. The grade of the canal has of necessity been kept low in order to prevent erosion of the light soil, and has resulted in the deposition of sediment and the encouragement of plant growth. As the climate is comparatively warm, nearly all of the agricultural products of the temperate zone and several of those of the semi-tropic zone are cultivated successfully.

In addition to the Calloway canal a large number of other canals of lesser importance are diverted from the Kern river in the neighborhood of Bakersfield. There are in all about 30 of the more important of these, the main canal lines of which aggregate about 300 miles in length and cover 475,000 acres of irrigable land, of which over 150,000 acres are now under cultivation. The whole area of land that may be covered by works from Kern river, therefore, foots up about 747,000 acres, of which about 475,000 acres is excellent irrigable land. Much of this, however, is really reclaimed swamp land.

Kern river has a slope through the valley of from 6 to 8 feet per mile, and lies in a shallow sandy bed, with banks of sandy soil 3 to 6 feet high. These favorable conditions enable water to be taken from it at almost any point at a minimum cost. No permanent dams or expensive headworks are necessary.

The Calloway canal is the property of the Kern River Land and Canal Company, and is diverted from the northern bank of the river, a short distance above the Southern Pacific Railway bridge at Bakersfield. (Fig. 67, *A*.) The water is diverted by means of an open wooden weir 400 feet in length, and extending across the entire width from bank to bank at right angles to its course. (Fig. 67, *B*.) This weir rests on rows of wooden piles driven 10 feet into the river bed, and consisting of 100 bays, each 4 feet in width between centers, composed of timbers set at an angle of about 40 degrees facing upstream and 50 degrees downstream. On the upper sloping face of these timber are grooves into which slide 1-inch planks or flashboards. These are inserted in sufficient numbers until at low water they fill the weir from base to crest, forming a continuous closed dam. At high water and in flood these planks are removed, one at a time, thus increasing the waterway of the flood to any desired amount. The total height of

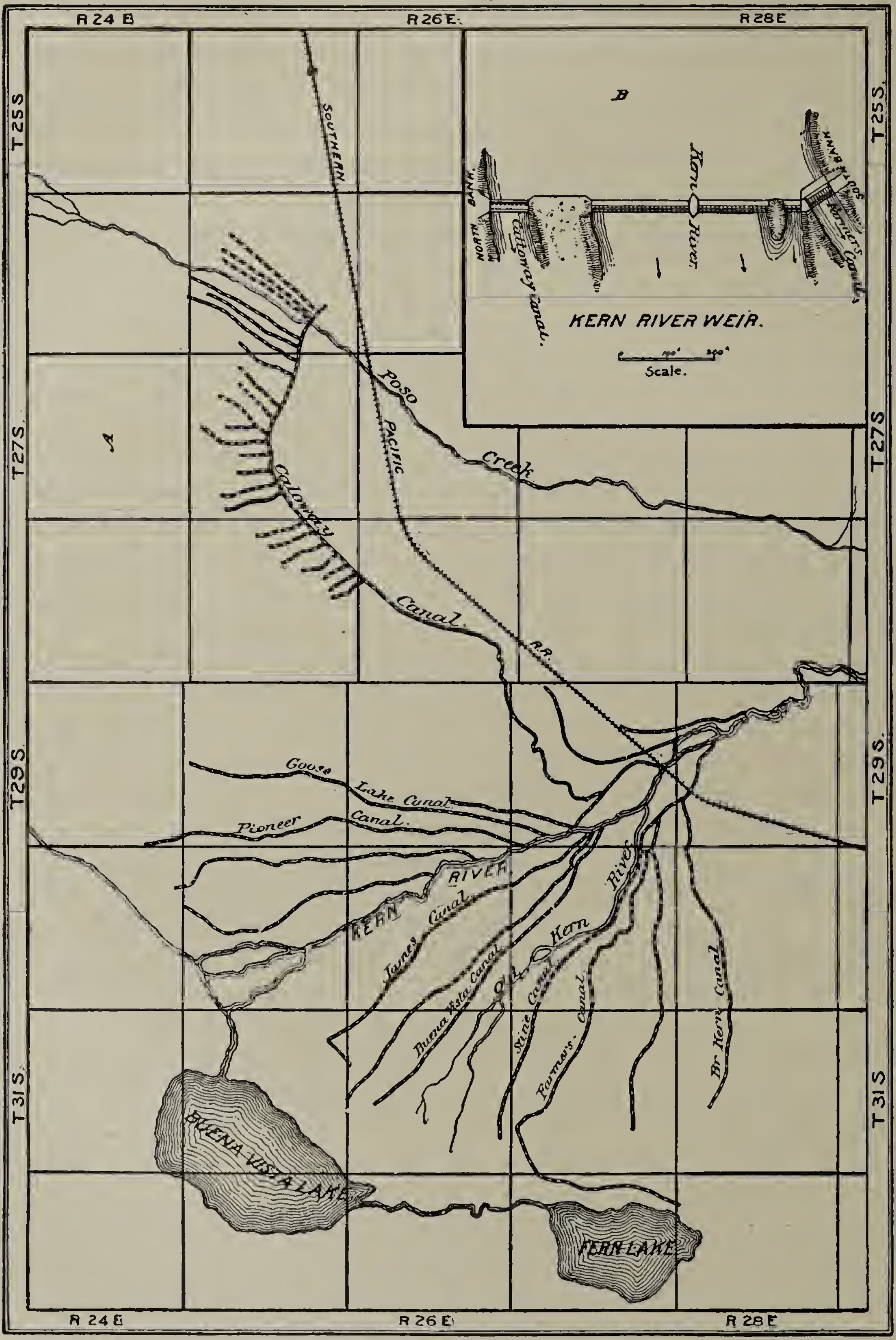


FIG. 67.—Calloway canal system, A, and plan of headworks, B.

the weir is 10 feet above its floor, and adjacent to its north end, and closing the head of the canal, is an open wooden regulator, constructed in almost exactly the same manner as the weir, but exceeding it in height by 1 foot. (Pl. CXXIV.)

Most of the Calloway canal is excavated in a light sandy loam which is exceedingly rich and fertile, but so light that the slopes given the banks are necessarily very low. The canal skirts the slopes of the foothills to the north on a changing grade, the object of which is to diminish its discharge as the various distributaries are diverted from it, while leaving it the same cross section in order that it may ultimately be enlarged. The grade changes from 0·8 of a foot per mile to the tenth mile, where it is lowered to 0·6 and then to 0·4 of a foot, and is finally level to near the end. This canal is 32 miles in length, its capacity at its head is 700 second-feet, its bed width is 80 feet, its surface width 120 feet, depth of banks 5 feet, depth of water 3½ feet, and maximum velocity 2½ feet per second. As this canal follows a gently sloping sidehill, it is built throughout its length half in cut and half in fill, the slopes of its banks being 1 on 3 inside and 1 on 2 outside, though, owing to the light sandy character of the soil, these have changed, until now the interior cross section is an easy-curved slope from the top of the bank to the center subgrade, as shown in Fig. 66, A.

At the second mile from the head is a double escape and regulating head constructed for the purpose of discharging all the waters at this point in case of necessity. In the thirtieth mile the canal crosses Poso creek, the first principal drainage encountered which is admitted to it by a level inlet, while in the opposite bank of the canal is constructed a wooden outlet weir. As the maximum discharge of Poso creek is about 3,000 second-feet, this outlet or escape gate is made of sufficient size to discharge this volume of water. Diverted from the Calloway canal are some 65 distributing ditches of from 8 to 20 feet bottom width, and from 1 to 9 miles in length, their aggregate length being 150 miles. These branches will carry 3 feet in depth of water, their banks have the same slopes as those of the main canal, and the grade is generally about 1·6 feet per mile. On the line of the distributaries, which of necessity run down the slope of the valley, numerous falls are constructed, the design of which is similar to that of the head weir, and their object is to maintain a uniform grade throughout the canal and keep its waters as near the surface of the land as possible.

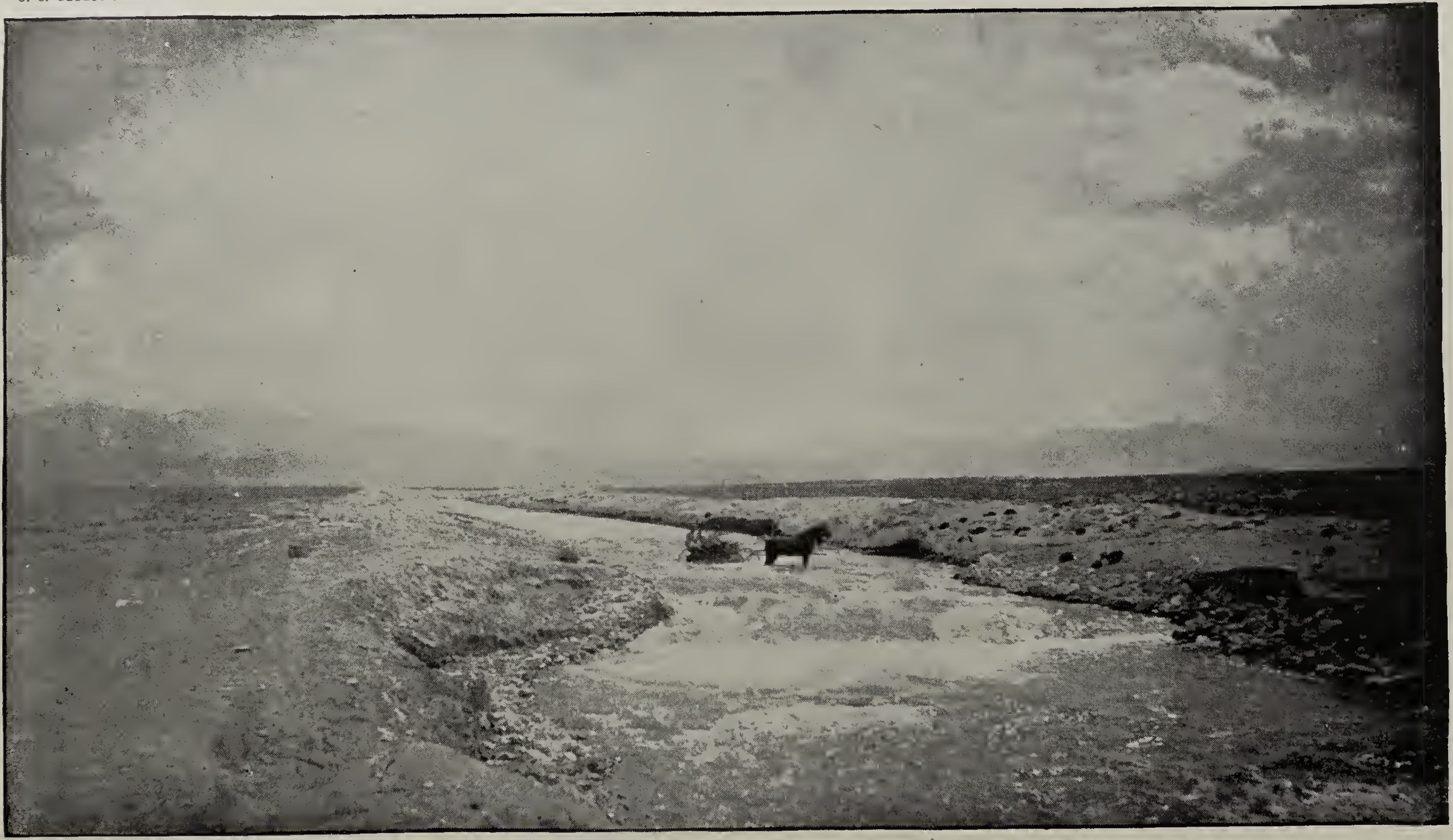
DEL NORTE CANAL.

This canal is situated in the San Luis valley, in southern Colorado, and derives its water supply from the Rio Grande at a point just north and west of the town of Del Norte. It is diverted from the left bank of this river, and after skirting the foothills north for a few miles is located around the western edge of the valley, commanding most of the lands between the Rio Grande and Saguache creek, of which it will irrigate about 225,000 acres, though the area commanded is much larger. The discharge of the Rio Grande at Del Norte, as shown by gaugings of the hydrographers of the U. S. Geological Survey, averages about 1,250 second-feet, and while its minimum discharge has been as low as 400 second-feet in the month of August, its maximum has reached at least 5,000 second-feet.

One of the chief points of interest in the construction of this canal was the rapidity with which the work was done. The preliminary surveys were begun on the 10th of December, 1883, and the canal was completed by the 1st of the following April. In the four winter months over 1,400,000 cubic yards of material were excavated to form the channel, requiring the employment of nearly 5,000 laborers and 1,200 teams, all in a sparsely inhabited country, and 220,000 feet of timber used in the construction of the canal was cut from the mountain sides, sawed, framed, and placed between the first of January and the first of March. The haste in construction was occasioned by the necessity to complete it in time to preserve legal rights and franchises.

The location of the head works is not the best that could have been chosen. They should have been placed at least 10 miles further down the river. According to the statement of Mr. Walter H. Graves, the engineer who built them, the selection of the present site was the result of other than engineering considerations. (Fig. 68, A.) The excessive grade consequently given in the first few miles of this canal is another curious feature of its construction. The line selected skirts the base of the foothills for the first 12 miles, and the canal is given a fall corresponding with the natural grade of the country. This is excessive for so large a work, averaging about 8 feet per mile until it emerges from the foothills, after which it is reduced to about 1 in 2112. As the channel is excavated almost entirely in a coarse gravelly drift and rock, no danger was anticipated from the erosive force of the current, though it was thought when constructed that it might in time be necessary to pave the channel, as no falls were put in it. Fortunately, this has proven unnecessary, owing to this steep descent being located on a perfectly straight line. In one place the grade is 35 feet per mile for a quarter of a mile, but even here little damage has been done by the high velocity. (Pl. CXII.)

The diverting weir (Fig. 68, B) is located at a point where the Rio Grande flows through a comparatively narrow gorge, having firm earth banks on one side and a rock bluff on the other. This weir has a total height above the grade of the river bed of 5 feet 6 inches. It consists of a series of open bays which are closed by flashboards, and it is almost identical in construction with the weir at the head of the Calloway canal, though a little more substantial. Its total length is 80 feet, and it contains seven openings, each 6 feet wide; the remainder of the weir consists of a rock and earth embankment, over which it is not intended that flood waters shall pass. As there are several channels to the Rio Grande just above the canal head, it has been necessary to construct wing dams and other obstructions for the purpose



DEL NORTE CANAL. VIEW OF RAPID.

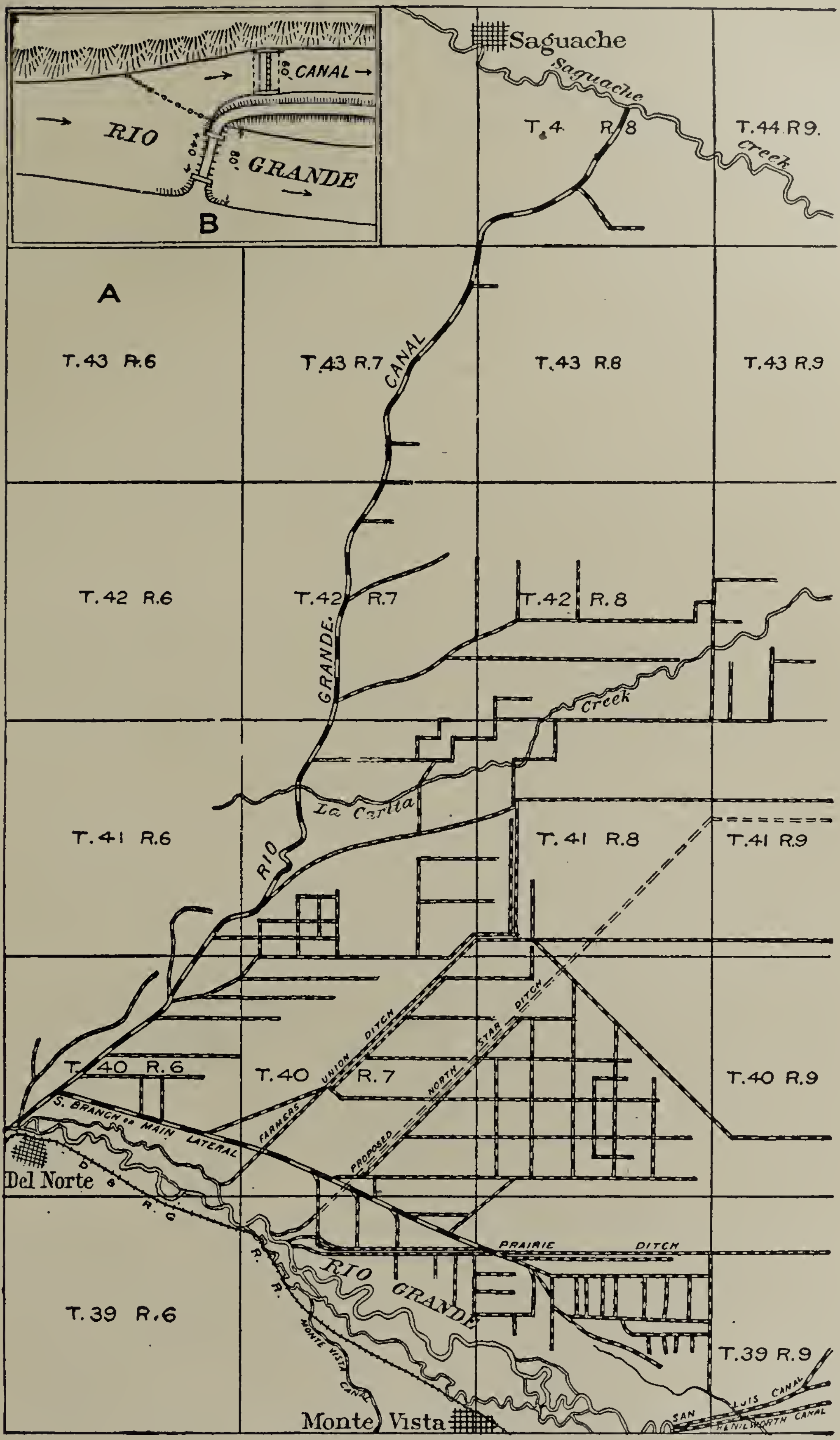


FIG. 68.—Del Norte canal system, A. and plan of headworks, B.

of training the main body of the river into the single channel which passes the head of the canal.

The regulator is situated back in the canal 100 feet or so below the entrance cut, and consists of a wooden structure having a heavy plank flooring resting on piles driven in the canal bed, and having wooden wings along its sides to protect them from erosion. It consists of ten gates, giving a width of 59½ feet of clear opening, and 8 feet in height. These gates slide vertically between guide posts, and are operated from above by means of screws with hand levers. (Fig. 98.)

For the first section of the canal below the head the bed width is 60 feet, depth of water 5½ feet to grade, with a subgrade of 1 foot. Its maximum capacity is 2,100 second-feet, which is greater than that of any other canal in this country. Eight thousand feet below the head is a bifurcation dividing the canal into equal branches, each having a bed width of 40 feet. (Fig. 69.) This bifurcation consists of wooden planking protecting the dividing point between the two canals and their outer sides and a wooden flooring resting on piles. In the head of each branch is a regulator by which the discharge into either channel can be controlled, and each regulator consists of five gates of the same general dimensions and form of construction as those at the head of the main canal. Lower down in the south branch is another bifurcation similar to that above, while numerous distributaries and smaller laterals are taken from both branches in such manner as to command most of the land below the canal and supply the private ditches. The fall in most of the branches in this canal is great, being from 10 to 15 feet per mile. In gravel this has caused little damage, but most of these distributaries are in earth excavation or embankment and have sustained much damage by erosion, necessitating the riprapping of large portions of their length. The engineer in charge of the work says, however, that it is cheaper to do this than to give the increased cross-section necessary with a less grade and velocity.

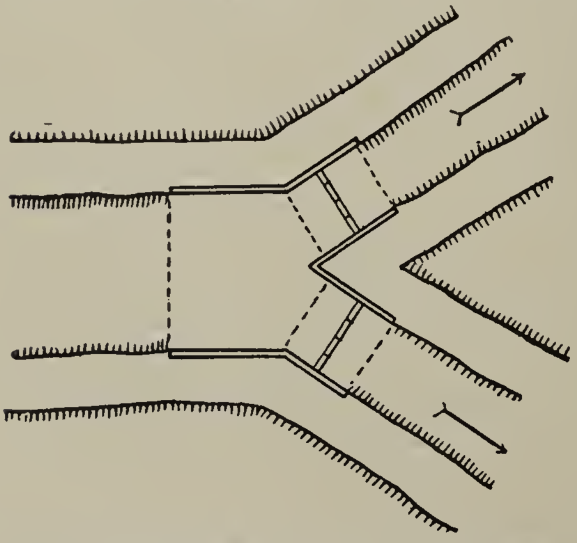
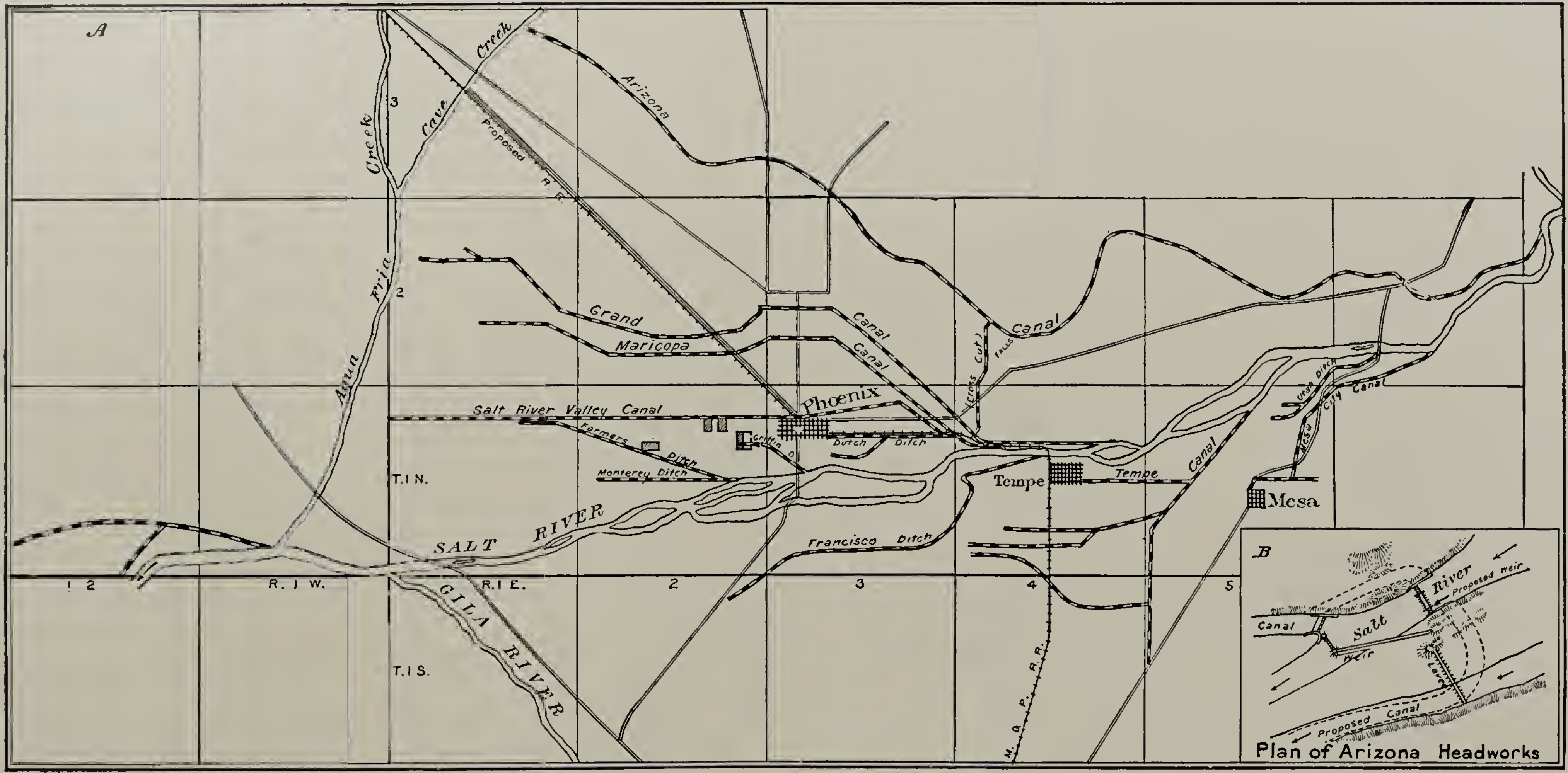


FIG. 69.—Del Norte canal. Plan of main bifurcation.

On the line of this canal are several works interesting in their design but simple in construction. One is a wooden aqueduct whereby the Farmers' Union canal, a separate irrigation channel, is carried over the south lateral of the Del Norte. The grade of this canal is kept high enough to give a clear crossing to the Del Norte canal, immediately after which the water is dropped in two falls of 3 feet each, constructed of wood, to the general level of the surrounding country. In another place a smaller canal is taken under a branch of the Del Norte



ARIZONA CANAL SYSTEM, A, AND PLAN OF HEADWORKS, B.

by means of a wooden box culvert or inverted syphon. (Fig. 114.) The cross-section of this canal is unlike that usually employed on canals in other countries and in most parts of this country. Owing largely to the light and sandy soil in which it is excavated, the banks have no fixed top width or outer slope, though this latter is about 1 on 3. The inner surface has side slopes of from 1 on 2½ to 3, and the bed of the canal is deepened toward the center to a subgrade of about 1 foot in depth.

From the accompanying map (Fig. 68, A), showing the canals constructed in the upper San Luis valley, it will be seen that two other independent main canals heading some miles below the Del Norte canal cross a large portion of the irrigable lands served by this work. Of these the Farmers' Union canal, a comparatively small structure, cuts right through a large body of the best irrigable country and serves a considerable area. There are already constructed in the Del Norte system about 50 miles of main canal and 130 miles of laterals, while the additional construction of the latter is being prosecuted as rapidly as settlement demands. The total cost of this canal was over $300,000, exclusive of the laterals.

ARIZONA CANAL.

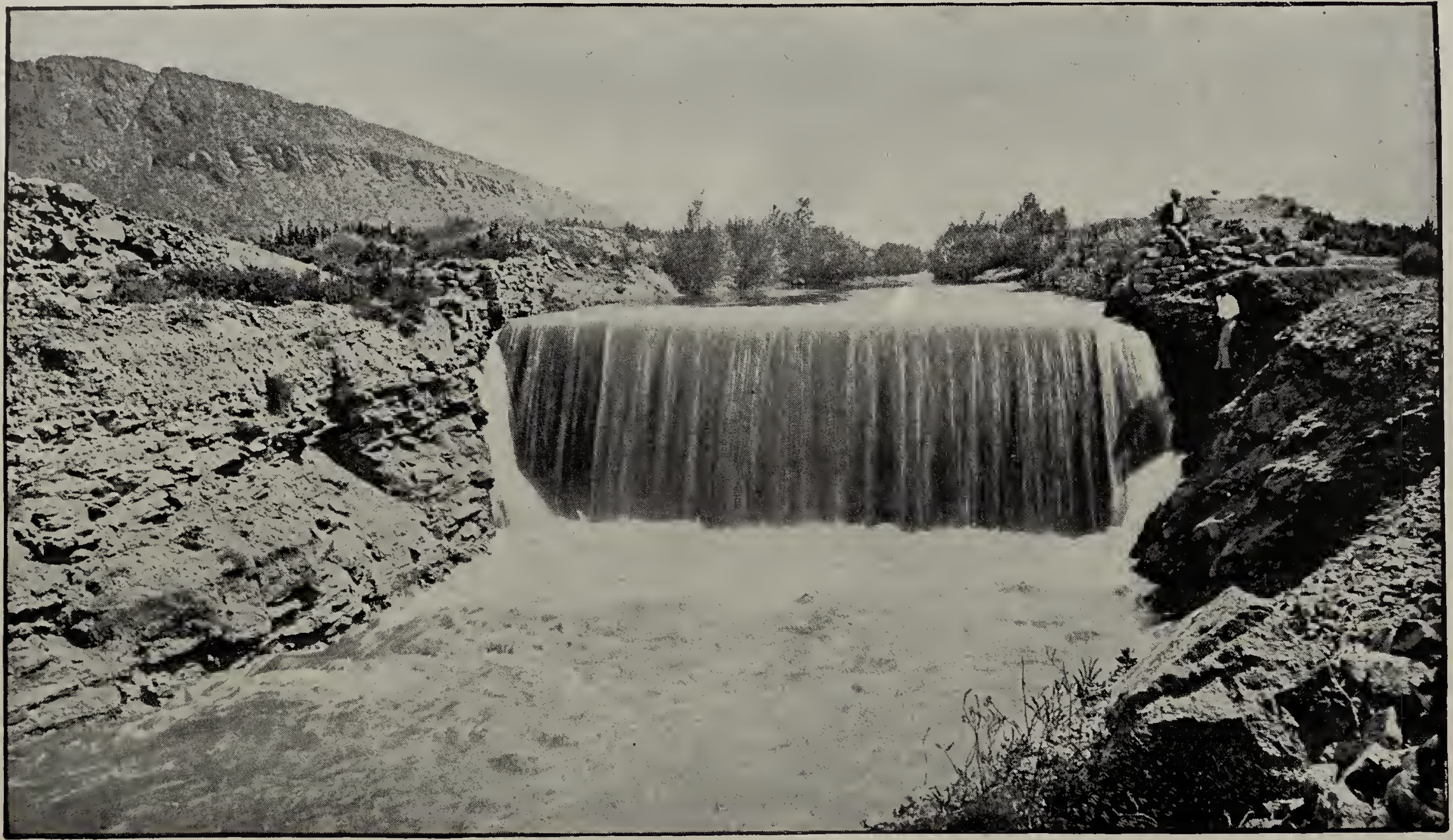
The Arizona Canal Company, of Phœnix, Arizona, owns and operates the largest system of irrigation works in that state and one of peculiar interest, owing to the extraordinarily high flood discharges of the stream from which the canal is diverted. The company was incorporated in 1885 with a nominal capital of $500,000, bonds for that amount being issued as part of the estimated total cost of $605,000. The main line of the Arizona canal was completed in 1887.

This canal is diverted from Salt river in southern Arizona at a point about 25 miles above the town of Phœnix and skirts the foothills on the north side of Salt River valley. It terminates in about the forty-first mile of its length at the Agua Fria river, which it is proposed soon to cross. In addition to the main Arizona canal the company now owns and operates three other lines of main canal which are older than the Arizona and were constructed previously to it, but have been purchased since. These are the Grand, Maricopa, and Salt River valley canals, and were originally diverted from the Salt river at points a few miles above Phœnix, opposite Tempe. (Pl. CXIII.) They follow the general slope of the valley and run nearly parallel to the Arizona canal between it and the Salt river. Since the acquisition of these properties by the main company their headworks, which were of a temporary character, have been abandoned and they are now fed from the Arizona or highline canal by means of a cross-cut, which runs down the slope of the valley at a point about 8 miles northeast of Phœnix.

The Salt river, a tributary of the Gila, has a far greater flood discharge than that stream. It receives the drainage from the larger portion of central Arizona, its principal tributary being the Verde river, which joins it at the head of the Salt river valley, about 26 miles above Phœnix. The drainage area of the Verde river above its junction with the Salt is 6,000 square miles. The drainage area of the Salt river, including the Verde catchment basin, above the head of the Arizona canal, is 12,260 square miles and according to observations made by the hydrographers of the U. S. Geological Survey its mean discharge varies between about 900 second-feet in the summer months and 10,000 second-feet in winter in average years. The mean discharge, however, was as low as 417 second-feet in August, 1889. The total monthly discharge of the river averages from 56,000 to 560,000 acre-feet and its run-off between .08 and .80 second-feet per square mile. The catchment basin of the river is subject to some of the greatest floods which have occurred in the west, due to cloudbursts falling over certain portions of the basin. In the early spring of 1890 an extraordinary flood occurred in the Salt river, increasing its discharge for a short period of time to 141,000 second-feet. This flood did much damage to railways and private property, but did not injure the canal. In the latter part of February, 1891, a still greater flood occurred in which the rise in front of the headgates reached 18½ feet. This extraordinary flood did much damage to the canal itself, washing out a portion of the headgates and several miles of its diversion line. The discharge of the river was estimated as being from 300,000 to 350,000 second-feet.

The head of the Arizona canal is situated at a point 1 mile below the junction of the Salt and Verde rivers, where the stream leaves the lower canyon, and flows between reefs of rocks which afford an excellent site for the weir and head works. Thence its course is along the north bank of the river, skirting the foothills surrounding Salt river valley and commanding an immense area of the finest quality of rich, arable land; where, owing to the semitropic character of the climate, abundant yields of hay, grain, vegetables, and such fruits as plums, peaches, grapes, and oranges are cultivated. The Salt river is an extremely difficult stream from which to divert a canal, owing to the irregularity of its discharge; for while its average minimum flow is usually as low as 500 second-feet, floods of from 10,000 to 20,000 second-feet occur annually. As a consequence of this erratic discharge the river bed itself is very wide and a long and expensive diversion weir is required in order to procure stability and permanence.

The weir at the head of the canal (Pl. CXXII) is constructed of crib boxes of rough-hewn logs, about 9 feet long each, drift-bolted, wired together and filled with rocks. The length of the weir is 916 feet and it is set at an angle with the current of the stream, the object of which is to give the most direct line of location between rock abutments, while the result has been to force the water over toward the canal head in a manner which is not altogether safe and satisfactory. The total height of the weir from the bed of the river to its crest is 10 feet for a little



ARIZONA CANAL. VIEW OF BIG FALL.

over half its length from the end adjacent to the canal head and 11 feet for the remainder of the way. The total width of the weir and apron parallel to the course of the stream is 48 feet and in the deepest part of he gravel bed of the river the depth of crib-work is 33 feet. (Fig. 86.)

At present the head of the canal is diverted at a point about 50 yards above the end of the weir from the right or western bank of the river and is separated from the end of the weir by two rocks which project above the river, and between which a waste or scouring gate has been constructed, the object of which is to prevent the deposit of silt in front of the canal head. The relative position of these works is such, however, that quite an island has formed almost in front of the head gates, which interferes with the free flow of water into the canal. The scouring sluice between the weir and the regulator is a simple wooden structure founded on piling and closed by flash-boards, and is very similar in its general design to those described for the open portion of the weir at the head of the Del Norte canal. The regulating gates at the head of the Arizona canal are well and substantially constructed of wood, and over the top of them, crossing the canal from bank to bank, is a covered bridge giving ample room in which to operate the gates.

At its head, and for the first considerable portion of its course, the canal has a bed width of 36 feet, carries a depth of 7½ feet of water and has a capacity of 1,000 second-feet. It is laid out with a uniform grade of 2 feet to the mile, its banks having slopes of 1 on 1½ in rock and its cross section being similar to that of the Del Norte canal, with no berme, and a subgrade of about 1 foot in depth. The main line is 41 miles in length and it is now being extended. For the first 3½ miles below its head excavation is entirely in rock or gravel, the gravel cut being 25 feet in places. Below this heavy work the canal is entirely in earth on a very gentle sloping side hill and is built half in excavation and half in embankment, with the exception of one short rock cut just above the diversion of the cross-cut canal. This cut is 15 feet in depth and has a fall built in solid rock 15 feet high, constructed both in order to drop the grade and to avoid some rock excavation and also with a view to being used for furnishing water power to be employed in the town of Phœnix. (Pl. CXIV.) About 1 mile below the head of the canal an escape has been constructed by which the discharge water can be let back into the river through a waste channel having a bed width of 40 feet and a length of 800 feet.

After it reaches the earth excavation below the heavy work the canal has a uniform grade of 1 foot to the mile, and is 30 feet wide on the bottom for a distance of 26 miles, having an 8-foot berme on the embankment side, the slopes of the banks being 1 to 1 in excavation and 1½ to 1 in embankment. In all cases the top width of the bank is 8 feet and its crest from 6 to 8 feet above the bed of the channel. All fills have extra widths and heights, giving them a secure appearance, while the curves are generally made very favorable and have been laid out with some attempt at intelligent alignment. In the first few miles the canal crosses several small drainage streams which have flood discharges of from 30 to 200 second-feet. These streams are admitted by simple level inlets, the water being passed on down the canal without any provision for wastage or escape, which is an undoubted defect in the designing of the work. Beyond Phœnix is a broad level stream bottom of considerable extent through which Cave creek finds its way, having a flood discharge of at least 1,000 second-feet. At present, owing to the difficulty and expense of confining this stream to a single channel, no provision is made for passing its flood waters, and when the floods occur they inundate a considerable area of country surrounding the canal on both sides, and necessitate upon their subsidence the reconstruction of quite a portion of the canal banks. In the twelfth mile from the head is a flume 1,200 feet long, spanning Kramer creek. This flume rests on oak pile bents capped with heavy timber and is well constructed and braced.

In addition to the 41 miles of main canal now existing there are the main feeder branches—the Grand and Consolidated canals before referred to. At about the twentieth mile of its course the cross-cut feeder is diverted from the main canal by means of two substantial sets of regulating gates, one of six openings in the main canal and the other of five openings at the head of the cross cut. These regulators are founded on sheet piling and are constructed of wood, the gates being operated from an overhead bridge by means of hand levers. The total length of the cross cut is about 4 miles, the bottom width 22 feet, slopes 1½ to 1, grade 2·65 per mile, and capacity 375 second-feet. As it is built straight across the country down its slope the total fall in its 4 miles is 128 feet. This drop is compensated by 28 falls, averaging about 5 feet in height each, and substantially constructed of wood on sheet piling. The checks in these falls (Pl. CXXXIV) consist of flash boards let in between posts, below which is an apron of wood 12 to 16 feet in length, while the banks of the canal are well protected by wings and sheet piling.

The first parallel feeder canal supplied by this cross cut is the Grand canal, below which the dimensions of the cross cut are slightly diminished until its terminus is reached at the second feeder, the Consolidated canal. The Grand canal has a bottom width of 20 feet, a depth of water of 3½ feet, and a fall of 2 feet to the mile, giving a velocity of 3 feet per second and a capacity of 210 second-feet. Its side slopes are 1 on 1½, and it is constructed about three-fourths in excavation. The dimensions of the Grand canal are a little greater than those of the Consolidated, which latter is bifurcated just below its head into two main branches, the Maricopa and Salt river valley canals.

The main Arizona canal has constructed about 125 miles of laterals, which command 77,000 acres of excellent arable land. The Consolidated and Grand canals are together about 70 miles in length and have 75 miles of laterals, covering 73,000 additional acres of land. It is difficult to ascertain the cost of the Consolidated properties, as they were constructed by various independent owners and by farmers. The main Arizona canal, however, exclusive of these branches and all laterals, but including the dam and other works on its line, cost $580,000, the laterals $25,000 more, and the improvements to the new dam an additional sum of $25,000, making its total original cost about $630,000.

During the three years that the Arizona Canal Company has been in operation it has paid interest charges at 8 per cent, it has paid off $105,000 of floating debt, and has redeemed and retired $102,000 of its bonds. It has also expended a considerable amount for permanent improvements and extensions and had a year ago $155,000 in its sinking fund, available only for the payment of the bonds which do not mature until 1900. It has sold only a small portion of its water rights, and of these only about a third are paying rentals. The maintenance charges on the main line and lateral, including taxes, office expenses, and all charges amount to about $18,000 per annum. Prior to the flood of February, 1891, which destroyed the headworks and a portion of the canal, the total cost of the works, including all expenses, was $700,000. A new location for the dam has been chosen (Pl. CXIII B), and one which it is hoped will be safe in the future from floods of any magnitude, and the line of the canal has been repaired. This work has doubtless increased the total cost of the canal system by from $50,000 to $75,000.

HIGHLINE CANAL.

A scheme for developing the lands lying in the proximity of Denver, by the construction of a canal diverted from the Platte river as it leaves the mountains, was talked of for some years prior to 1880. The actual work of construction, however, was not commenced until that year, and was completed in 1883, when water was furnished those who demanded it. The designing and construction of this work was under the personal supervision of Mr. E. S. Nettleton.

The Highline canal is diverted from the South Fork of the Platte river, in the narrow rocky canyon, about 21 miles above Denver. As shown by gaugings maintained on this stream during a period of about three years, the maximum discharge which occurs from the middle of May to the end of August averages about 700 second-feet, though its highest known flood mark indicates a discharge of somewhat over 2,000 second-feet. Its minimum recorded discharge is 100 second-feet and its average about 400. As a consequence, though the cross section and capacity of the canal is large, the water supply is not equal to the demand during most of the irrigation season. This fault could, however, easily be remedied by the construction of storage reservoirs on the upper branches of the stream, several excellent sites for which have been discovered and a few surveyed.

The diversion weir is 14 feet in maximum height, 117 feet long, and 6 feet wide on top. It consists of crib work filled with rock, and whereas the upstream slope is very flat, the downstream face is nearly vertical. Near the left bank is constructed a substantial masonry undersluice, open the entire depth of the weir, whereby the water in the river above may be drawn down to any desired level. The sluiceway consists of four iron gates, each 4 feet wide between centers and 7 feet in height. These gates are raised by means of screws, and the sills of the gates are placed at a distance of 4 feet below the level of the head gates of the canal, in order to permit of sluicing out sand, etc. (Fig. 87.)

The canal is diverted from the right bank, just above the weir, the head regulator consisting of a set of five gates, each 6 feet in height and 3½ feet wide between centers. This head regulator is constructed between solid rock walls, and the gates, which are of wood, are raised by screws from a platform above. Immediately below the regulating gates is a tunnel excavated in granite, 600 feet long, 20 feet wide, and 10 feet in height in the center, the lower end discharging into a great wooden bench flume, which skirts the steep, rocky slope of the Platte canyon for a distance of 2,640 feet, where it terminates in the open canal excavation in which the water is carried throughout the remainder of its course. At the head of this flume (Pl. CXXXV) and at the lower end of the tunnel is an escape, by which the volume of water carried in the canal can be regulated. This escape consists of five wooden gates, each 3 by 4 feet, and raised by rack and pinion, while immediately below them, across the entire width of the flume, are a set of check or flash boards about 2 feet in height, which act as a sand gate by causing the silt to deposit immediately above them, when it can be scoured out through the escape gates.

The great bench flume which extends for over a half a mile below the tunnel is 28 feet wide and 7 feet deep; its grade is from 5 to 8 feet per mile, and its discharge, which is the same as that of the canal proper, is 1,148 second-feet. The main canal is 51½ miles in length, and from it are diverted two main branches, the first at the fourteenth and the second at the twentieth mile of its course. At its head the main canal is 48 feet wide on the bottom and from 7 to 8½ feet in depth, with slopes of 1 to 1 in cut and 1 on 2 in embankment and with a uniform grade of 1·76 feet per mile. At the end of the canal it is bifurcated, a branch being led off in a northerly direction following nearly the grade of the country for some distance and then on a regular fall of 3½ feet per mile with a width of from 15 to 20 feet at the bottom. The main canal beyond the fifty-first mile has been carried 20 miles further and the northern branch 12½ miles, making the total length of the main line 82½ miles, exclusive of the two smaller branches above referred to.

The line of this canal is crossed by several side gulches or torrents. In the first mile is an embankment 18 feet in height at a gulch crossing, but as the discharge of this is small there is no inlet or outlet dam constructed for the regulation of its flow. In the third mile Willow creek is crossed by the construction on the lower side of the canal of a heavy earth embankment which is 30 feet high and 8 feet wide on top, with slopes of 1 on 3 inside and 1 on 2 outside. Above and below this embankment escapes are constructed in the canal banks which discharge directly over the natural gravel slopes of the country into Willow creek. These escapes have lengths of 200 and 300 feet, respectively. At the ninth mile Plum creek is crossed by a flume 918 feet long and 18 feet in height on a high trestle founded on eight rows of 12-foot piles. In this flume are four sets of escape gates spilling into Plum creek by which the discharge of the canal can be regulated.

The fall of the river at the point of diversion of the canal is excessively rapid, the grade being nearly 150 feet per mile. As a consequence of this, though the tunnel is but 600 feet long, the upper end is at the level of the river water, while the lower end is over 30 feet above it. The cost of the tunnel was about $30,000. In the construction of the bench flume several rock cuts were made ranging from 5 to 70 feet in height, and the excavation of this bench cost about $50,000. The flume laid on the bench cost $16,000, and the excavation of the main canal amounted to nearly 2,300,000 cubic yards of earth and 66,000 cubic yards of rock, and cost in all about $355,000. Exclusive of the 480,000 feet of timber in the bench flume there are about 4,263 linear feet of flumes on the line of this work, and with the benches, bridges, etc., the total amount of timber used exclusive of that already mentioned aggregates nearly 2,000,000 feet, at a cost of about $70,000. The total cost of both the original and the new weir, the bench flume, the canal, and all other works amounted to about $650,000, and the maintenance cost and other charges amount to about $25,000 per annum, including salaries, office expenses, etc. The canal commands about 90,000 acres of excellent land in the suburbs of Denver, though but a small portion of this is irrigated by it owing to the lack of water.

WYOMING DEVELOPMENT COMPANY'S CANAL.

The water supply for this system is derived from the Big Laramie river in Albany county, in Wyoming, from which it is diverted by a weir and passed by a tunnel through a dividing ridge, and permitted to flow down Blue Grass creek, which is one of the head waters of Sybylle creek. From this it is again diverted in Laramie county, and delivered by means of two main canals to the irrigable lands.

These canals irrigate a portion of the land between the Sybylle and Chugwater creeks on what are known as the great Laramie plains. They lie at an average altitude of 4,800 feet, and while the climate is favorable to the growth of forage crops, small grains, and some vegetables, it is too cold for the cultivation of fruits and the more tender vegetables. At the point of diversion the Big Laramie has a maximum discharge in times of flood of about 8,000 second-feet, while its minimum discharge is as low as 100 second-feet at the lowest stage of summer flow. The discharge of Sybylle creek falls as low as 30 second-feet, though it averages considerably more than this during the irrigating season. The minimum flow of these streams during the irrigating period may be readily increased by the construction of cheap storage reservoirs, many sites for which are known.

The main supply canal is diverted from the Big Laramie river at a point about 120 miles north of Cheyenne. (Fig. 70, A.) The water is diverted from the river by means of a crib and stone dam 150 feet in length, resting on the coarse bowlder and gravel bed of the river. The maximum height of the diverting weir is 4 feet, its top width being 16 feet, with a 4-foot vertical drop on the downstream side to an apron 16 feet in length, composed of logs laid parallel to the course of the stream. (Fig. 70, B.) The canal heads at the south end of the weir, and is regulated by a series of 6 wooden gates each 5 feet wide and 9 feet in height, and operated by lever and ratchet. The first 2,000 feet of the canal consists of an open canal and approach cut in gravel, having a 30-foot bed width, and capable of carrying 8 feet depth of water. Its grade is 7 feet per mile and its side slopes ½ to 1, the discharge capacity being 650 second-feet. This open cut terminates in a tunnel carried through a portion of the divide which separates the Big Laramie from Blue Grass river, and tails into a short branch of that stream. The tunnel is in gneiss rock, unlined, and has an approximate cross section of 7 by 8 feet, and is 3,100 feet in length, with a grade varying from 50 to 100 feet per mile. The terminal cut at the exit of the tunnel is in rock 25 feet in maximum depth and 1,000 feet in length, the fall being 450 feet per mile

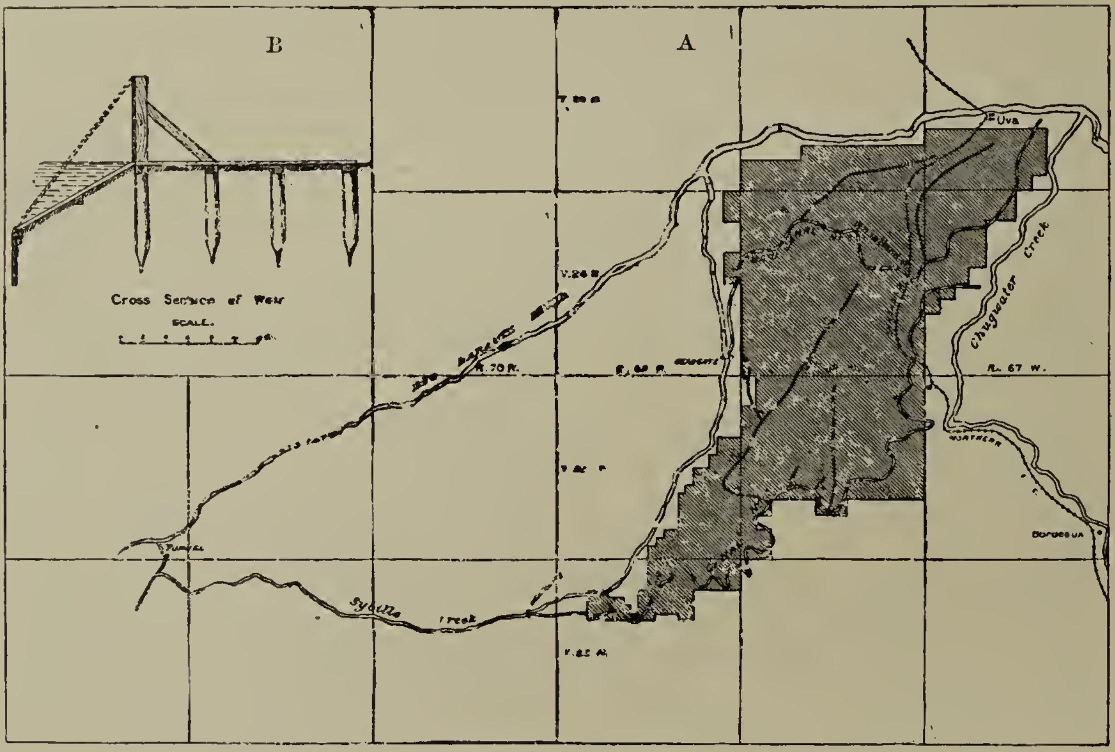


FIG. 70.—Wyoming Development Company's canal system, A, and cross section of weir, B.

and the bottom width 8 feet. After being discharged into Blue Grass creek the water flows down this stream for a distance of 13 miles to its junction with Sybylle creek, down which it flows a farther distance of 1½ miles to a second diversion weir constructed across that stream. In Blue Grass creek the total fall is 1,700 feet over a rock bottom and through a narrow and treacherous channel, and in Sybylle creek it falls an additional 30 feet.

The diverting weir in Sybylle creek is constructed of wood founded on piling driven in the river gravels. The form of this weir is similar to the open weir described for the Del Norte canal, and consists of eight bents, each 8 feet long across stream and 8 feet in height, closed by flash boards presenting a vertical face upstream. The two banks of the river are protected by wooden planking for a distance of 12 feet upstream and 18 feet downstream. The second length of the canal heads above this weir, and is controlled by a set of regulating gates of the same dimensions and general form of construction as those described for the first section of the canal, but having a total width of 25 feet, disposed in five gates each 5 feet between centers, and built as a continuation of the diverting weir. This second section of the canal, which is the main distributing canal proper, is 34 miles in length, and is constructed for the first 20 miles of its course in gravel and hardpan, with much difficult side-hill work, some cuts being as deep as 40 feet. Its bed width is 25 feet, slopes 1 to 1, depth of water 5 feet, and grade 2 feet per mile. In its course it encounters considerable side-hill drainage, all of which is let into the canal by simple inlets, while wasteways or escapes, closed by simple flash-board regulators, are constructed in the opposite bank of the canal, their discharging capacities varying according to circumstances up to an extreme width of 30 feet. A few miles below the head of this main canal a main lateral is diverted, controlled by a simple flash-board check built in the main canal. About 12 miles below the head of the main canal a second main distributing canal is diverted from Sybylle creek by means of a weir similar to that just described, the height of which is 5 feet and its length 40 feet. This canal is 20 feet wide at the bottom, depth of water 4½ feet, slopes 1 to 1, and grade 2 feet per mile. It is 20 miles long and encounters some very heavy side-hill work in the first few miles.

The total cost of this work to date, exclusive of the construction of laterals and of some of the second main canal, which has not yet been built, amounts to about $485,000. At present the company offers its lands for sale at from $4 to $8 per acre, in addition to which price water is sold at reasonable rates per acre irrigated. Though completed in 1885, this canal has never been utilized, owing to complications concerning land titles. A way will doubtless soon be found to utilize the abundant water supply which this work is capable of bringing to the rich lands now covered by it.

KRAFT IRRIGATION DISTRICT CANAL.

This canal was constructed to irrigate the lands of the Kraft Irrigation District, which was organized in 1888 under the Wright law. This District is located on the north side of Stony creek in the counties of Colusa and Tehama and is well adapted for irrigation, as the soil is light and porous and the surface smooth, with a gentle slope of 8 or 9 feet to the mile toward the Sacramento river. The lands are situated between Stony and Dry creeks, the former of which is a river in size,

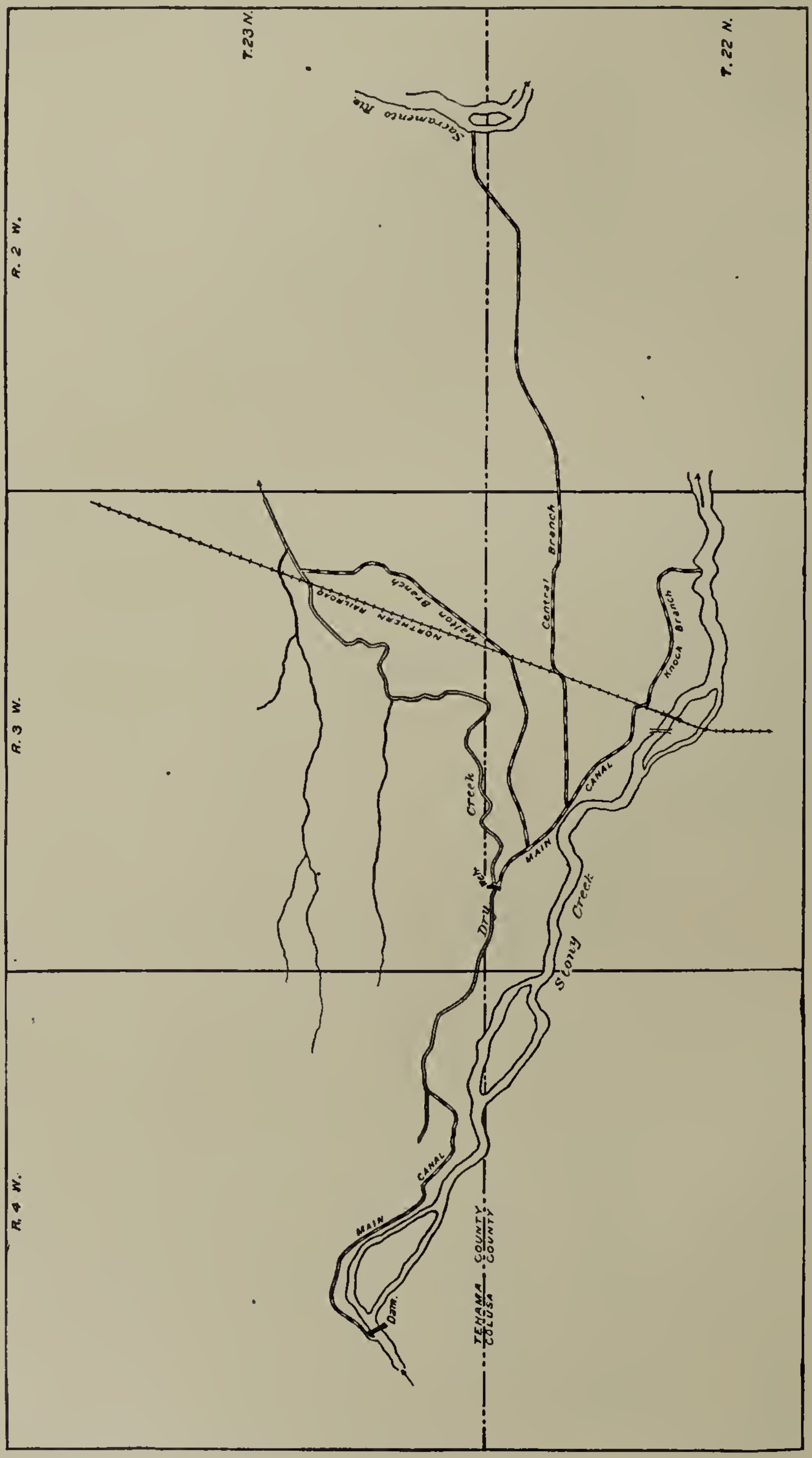


Fig. 71.—Kraft Irrigation District canal system.

rising in the Coast range near Clear creek. (Fig. 71.) It drains a watershed of about 740 square miles in these mountains, on which the rainfall averages 25 inches per annum. Its maximum discharge is about 20,000 second-feet, its minimum 30 second-feet; its average discharge ranges from 500 to 1,000 second-feet, more than sufficient to supply the ordinary demands of the canal. There can be no question as to the reliability of Stony creek as a source of water supply.

The Kraft district comprises 13,500 acres, of which about 12,000 acres consist of good irrigable land. This section is capable of producing any kind of fruit grown in California, and much earlier than in many of the southern counties. The bonds for the district were voted to the amount of $80,000, or $6 per acre, and as the assessed value of the district is $250,000, or three times the bonded indebtedness, it will be seen that this district has a good financial foundation. As soon as the bonds were floated in January, 1888, preliminary surveys were made for the district by Mr. C. E. Grunsky, chief engineer, to serve as a basis for estimates of cost. Mr. Grunsky designed and estimated all of the details of the works on this canal with more care than is usually taken on such works in the west, and like those of the Central Irrigation District they serve to mark an advance in the science of irrigation engineering in this country.

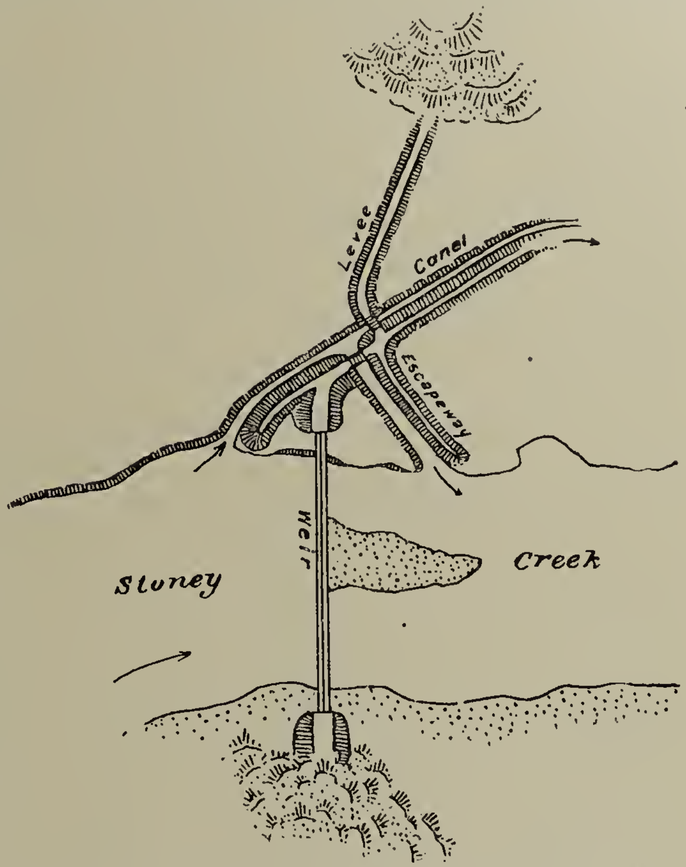


FIG. 72.—Kraft Irrigation District. Plan of headworks.

A diversion weir will be built across Stony creek, where it flows between two buttes and starting from bed rock will be about 16 feet in height, thus raising the water about 4 feet above its ordinary level. (Fig. 72.) This weir will be about 500 feet in length, built of heavy timber after the crib style. The main canal which heads at the weir will will be 16 feet in bed width and will carry 3 feet in depth of water, while its banks will have slopes of 1 on 2 inside and 1 on 3 outside, its uniform grade being 4 feet per mile. From the weir the canal runs along the north side of Stony creek in an easterly direction for 2 miles, after which its bed width is narrowed to 10 feet, depth of water increased to 4 feet, and slopes changed to 1 on 1, the grade remaining the same. Just opposite the head gate of the canal is an escape-way discharging back into the river. About 1,800 feet below the head is a second escape-way returning water into the river through a small natural-drainage channel. In the first 4 miles of this canal there are 7 escape-ways by which surplus water, or that carried into the canal from the drainage which it crosses at level, can be passed back into the river.

At the fourth mile from its head the canal empties into Dry creek, down the channel of which the water flows for 3 miles to a diversion weir thrown across the channel of that stream. The canal is here taken out on the south side of Dry creek and follows the interfluve between Dry and Stony creeks for the remainder of its course. Its dimensions after leaving Dry creek are the same as at its entrance; its capacity throughout being 150 second-feet to about 3,000 feet below the Dry creek weir, at which point the canal bifurcates, the northern or Malton branch extending for 5½ miles and tailing back to Dry creek. (Fig. 71.) This northern or Malton branch has had a bed width of 12 feet for the first 2 miles of its length, after which it is reduced to 10 feet.

The southern branch is again bifurcated about 4,000 feet lower down. The northernmost of these two branches, known as the Central branch, has at first a bed with of 14 feet, which is reduced to 12 and then to 10 feet; its length is about 9 miles and it tails into the Sacramento river through an outflow box. The southernmost or Knock branch has a length of about 3 miles and a bed width of 12 feet, its terminus being into Dry creek. As before stated, the Weir across Stony creek is a timber crib-work filled with gravel, the frames of which are planked on both faces. The escape or subdrainage water is permitted a clear flow under the dam and apron, beyond which it rises and flows over a second apron. By this means no pressure is exerted upon the main dam and apron. This structure is a solid check weir, with no scouring sluices through it. The location of the escape and regulating gates at the head of the canal and the general arrangement of the head works are shown in Fig. 72. From this it will be seen that in addition to the main weir across Stony creek a levee has been built on the opposite side of the canal, thus closing the low bottom land from hill to hill. The main waste gate is a wooden structure built somewhat after the crib fashion, its sides protected by piling which is planked, while underneath it is driven a row of sheet piling to prevent seepage.

As the slope of the country down which this canal flows averages about 3 feet per mile, it has been necessary to introduce a large number of check weirs or falls to neutralize this inclination. There are in all about 40 escapes, regulators, and falls on the line of the main and branch canals. The construction of these falls is very similar to that of the regulating gates, and consists of piles driven into both banks and faced with planking to protect them against erosion, while the bottom or flooring rests on piles across which the floor timbers are laid, thus making the regulator somewhat like a box flume. In this is inserted the upright supporting the gates, which are generally 4 feet in width. As seen in Fig. 73 the bed of the canal is excavated below the falls only a sufficient amount for the building of the canal banks, as it is intended to permit the water of the canal to cut down to grade, as it surely will in a very few years.

The total cost of the excavation of this canal is estimated at $30,800, and that of the structures, including the dam, regulating gates, falls, engineering expenses, etc., $31,440, making the total estimated cost of the work $62,240, or but $4·62 per acre.

PECOS VALLEY CANALS.

The Pecos river is a mountain stream subject to alternate flood and drought until it reaches the neighborhood of Roswell, New Mexico, whence, for a distance in a straight line of about 100 miles in a due southerly direction, its course is so tortuous that the length of the river is probably 250 miles. This portion of the river is fed by numerous springs which generally enter it along its bed following the limestone strata of the country.

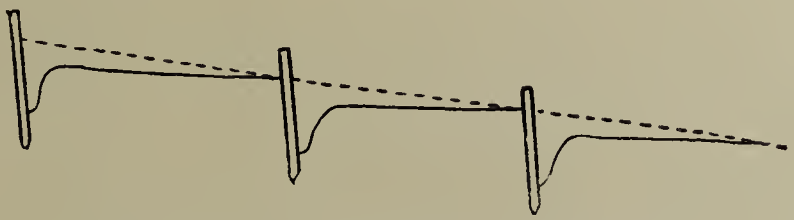


FIG. 73.—Kraft Irrigation District. Excavation for fall.

The rainfall in the lower Pecos valley is from 12 to 15 inches per annum, though it is much greater than this higher up the valley and somewhat less as the river enters Texas. The rain occurs mainly in June, July, and August in the form of showers and is extremely variable and uncertain. The Pecos river is nearly dry as far as Roswell, at which point it receives its true perennial supply, which is from the numerous springs and small rivers above Roswell. The Berenda river, and the North Spring and South Spring rivers add each about 50 second-feet to the discharge of the Pecos, while the Hondo river has a discharge of about 48 second-feet above its junction with the Spring and about 200 second-feet at the point at which the northern canal is diverted. It will be seen that the perennial supply of water in the Pecos is derived from springs which, from their permanence of discharge, must receive their supply from some great distance. In addition to this perennial discharge, which is of some magnitude, the river discharges large flood volumes during a portion of the spring and summer months.

The lands of the Pecos valley between Roswell, New Mexico, and Pecos, Texas, are broad and level, and are probably the best in the state. They are of the choicest limestone soil and their total area is nearly 1,000,000 acres, of which fully 400,000 acres are below the level at which it is practicable to deliver water from the Pecos. The lands of the Pecos river may be divided into two principal divisions. The first extends to Seven rivers and broadens out into a plain containing thousands of acres of fine agricultural land. On the east side of the river powerful springs occur at short distances across the plains from west to east below Roswell, forming deep streams, which are from 30 to 60 feet wide, and constitute the Hondo river, a branch of the Pecos. This is the water supply of the upper canal system, which is here entirely independent of the Pecos. The second section of the river extends from the canyon, 8 miles above Eddy, to some distance below Pecos city, Texas. This portion of the valley of the Pecos is from 25 to 30 miles in width and contains the richest agricultural region in the Pecos valley; it is a plain covered with a soil of fine dark loom from 16 to 20 feet in depth.

To irrigate the lands of the Pecos valley two companies have been organized within the past few years and have constructed three separate systems. The more important of these corporations, the Pecos Irrigation and Improvement Company, has built three dams, at which head the three most important canal systems in New Mexico. The Northern canal consists of a dam across the Hondo river below the junction of the North Spring and Berenda rivers, 5 miles east of Roswell, whence the canal runs southeasterly and southerly to where it crosses the South Spring river, at which point a pick-up weir is built which turns the water southward through the main canal to the Feliz river, a distance of 25 miles, bringing under cultivation 60,000 acres of fine agricultural land. This canal is now being extended to a length of 50 miles, and with the construction of proper storage reservoirs may be extended so as to irrigate 100,000 acres more of equally productive land, reaching to Seven Rivers, in Eddy county.

The middle dam of this company is built across the Pecos river below the canyon, about 6 miles north of Eddy, and from it a main canal runs along the east bank for a distance of 4 miles to a bifurcation, whence the principal branch crosses the river on a flume and extends down the west side of the valley for a total length of 55 miles, terminating at the Delaware river and bringing under irrigation at least 150,000 acres. (Fig. 74.) The eastern branch extends for a distance of 20 miles down the east side of the valley, terminating in a dry lake and bringing under irrigation 50,000 acres. A part of this same system is a short branch called the Hagerman canal heading on the east side of the river 15 miles below Eddy, and having on its line a large storage reservoir, which is about 1½ miles wide, with an average depth of 25 feet. The third or southern canal system of this company is now being constructed, the water to fill it being diverted from the Pecos river by the construction of a large dam in Texas just south of the territorial line. This canal, when completed, will be 25 miles long and will irrigate about 70,000 acres of land in the state of Texas.

The middle canal of the Pecos Irrigation and Improvement Company heads below the canyon a few miles above the town of Eddy. It is diverted from the Pecos river by means of a great dam built of loose rock and earth, 1,600 feet in length on its crest and 50 feet in maximum

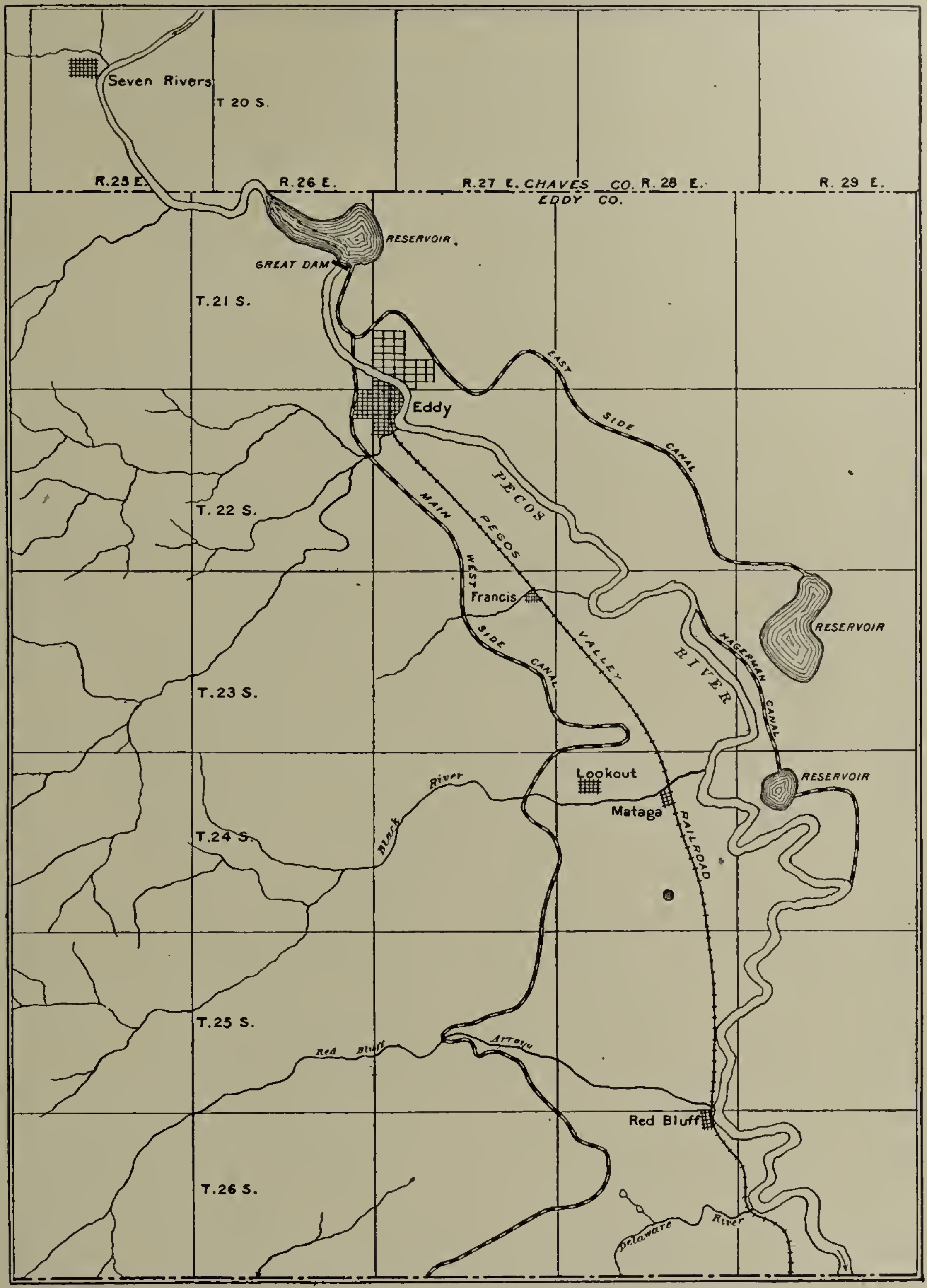


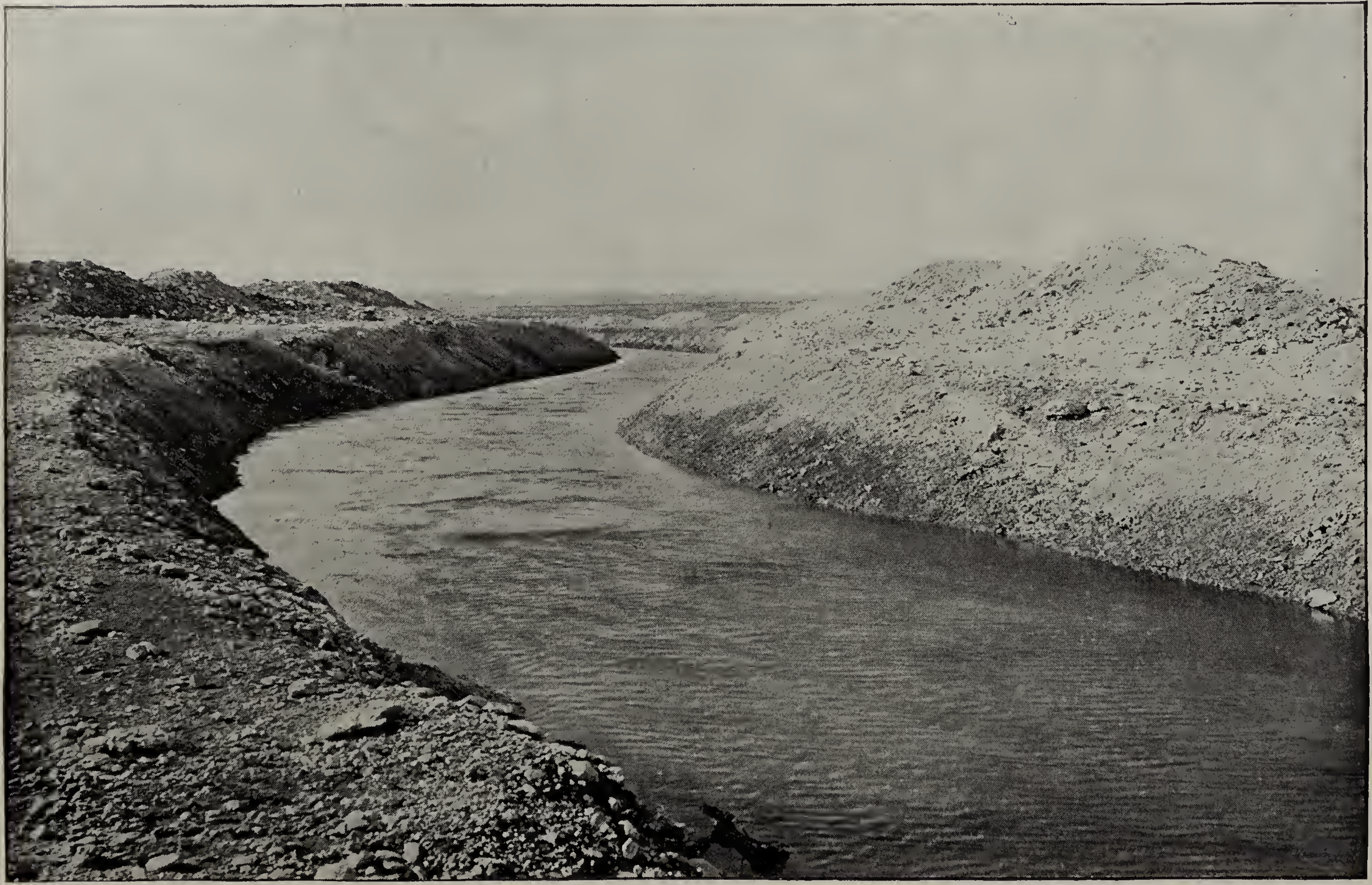
FIG. 74.– Pecos canal system.

height. This dam follows a gap or notch worn through a solid limestone ridge, and hence its abutments and foundation are of solid rock. In addition to acting as a diversion weir it forms a great storage reservoir about 7 miles in length and 1¾ miles wide, the capacity of which is claimed to be 23,000 acre-feet, though but a small portion of this can be used for supplying the canal, as the sill of the head gates of the latter are but 20 feet below high-water mark in the reservoir, and thus only that depth of water is available. (Pl. CXXVII.)

The canal heads at the east end of the dam in a rock cut 30 feet wide, 25 feet deep, and 500 feet in length, which has a waste way for the discharge of the surplus waters of the reservoir at its entrance and an escape way at the lower end of the cut and below the regulating head in the canal, which latter is placed in the cut. The main canal below the rock is cut 45 feet wide at the bottom, 70 wide on the top, and has side slopes of 1 on 1½, and will carry a depth of 6 feet of water. Its grade is 16 inches per mile and its capacity about 1,100 second-feet. It is excavated throughout in a light sandy loam. The first portion of this main canal is 4 miles in length to the bifurcation, and both in this and in the lower portion of its line the embankment is thrown up wholly on the lower side, wherever the canal is in sidehill excavation, so that the floods caused by arroyos entering the upper side become ponds or reservoirs, in which the waters of the canal spread out. Were water more valuable at present this would be a decided disadvantage, as the loss from the seepage and evaporation is very great in such places.

At its entrance to the canal the water is controlled by means of two sets of regulating gates. The main set at the head of the rock cut consists of six gates, each 5 feet wide by 9 feet high, and operated by a male screw attached to each gate, on which a female screw is turned from above. The gates are of wood, 6 inches in thickness, and slide between wooden posts, each 12 by 12 inches. The discharge capacity of the entire regulator is 3,000 second-feet. At the lower end of the rock cut and at the head of the canal proper is another set of gates, four in number, which can not be lowered when the cut is full of water, but can be dropped in case of necessity. Adjacent to these are a set of ten escape gates, each 7 feet wide, giving a clear escape way 70 feet in width back into the river. At the point of bifurcation 4 miles below the canal head are two sets of regulating gates. That at the head of the eastern branch contains six openings and the one at the head of the western branch seven openings, each 15 feet in the clear, while between the two is an escape gate consisting of five openings, each 5 feet in the clear, which discharge the water through a short channel back into the Pecos river below the flume.

From the bifurcation the canal crosses the low valley of the Pecos river and that stream itself by means of a high terreplein or raised earthwork embankment and a great wooden flume. The first terreplein, that leading to the river, is 1,600 feet long and 105 feet wide at the base and has a maximum height of 24 feet. The terreplein on the west bank of the river is 300 feet long, and is likewise 24 feet in maximum



PECOS CANAL.

height. Between the two is a flume the length of which is 475 feet. Its width is 25 feet and it carries 8 feet of water. (Pl. CXXXVIII.)

Below the crossing of the Pecos the west branch has a bed width of 25 feet, slopes of 1½ to 1, carries a depth of 6 feet of water, and has a uniform fall of 18 inches to the mile. This canal (Pl. CXV) passes about 1½ miles west of Eddy and follows along the main portion of the valley for 8 or 10 miles back from the river, and is at present completed as far as Black river, across which a high flume is about to be constructed. In addition to the main canals connected with this system there are at present constructed over 100 miles of laterals, each from 4 to 6 feet wide and carrying a depth of from 1 to 2 feet of water, while several hundred additional miles of these are to be built in the immediate future.

The main storage and diversion dam cost $90,000; the remainder of the works, $400,000, in addition to which $800,000 is invested in a railway 90 miles long and other improvements for the development of the property of the company. The capital of the company is $1,300,000, while its contracts for water rights, payable in cash and 8 per cent mortgage notes due within six years, cover about one-third of the total cost. A perpetual water right can at present be purchased from the company at $10 an acre, payable in ten annual installments, in addition to which the annual water rental is $1·25 per acre.

CENTRAL IRRIGATION DISTRICT CANAL.

This district is situated in the northwest portion of the Sacramento valley, California, and embraces nearly 245 square miles of area. The district was organized on December 31, 1887, under the Wright irrigation law. In 1890–'91 the assessed values of property in the district reached the sum of $2,720,700. Prior to the construction of the Central irrigation canal the lands in this district were used almost exclusively for the cultivation of wheat, grain, and hay, and for this purpose the average value of farming lands was $13·97 per acre, though quite a portion of the better lands were valued, less improvements, at about $60 per acre.

At the election for the issuance of bonds in April, 1888, a bonded indebtedness to the amount of $750,000 was incurred by vote of the whole district, and to date bonds to an aggregate value of $323,000 have been sold.

The northern end of the Central irrigation district is 38 miles south of the upper end of the Sacramento valley, and it extends 38 miles southward. The east boundary of the district follows section lines at a distance of from 4 to 5 miles west of and parallel to the general course of the Sacramento river. Its western boundary is the main supply canal which is practically a grade contour. The general width of the district is from 6 to 9 miles, and its area 156,550 acres. Of this land about 140,000 acres are already under cultivation in grain crops. The land, however, is excellently adapted, with the aid of irrigation, to the cultivation of such fruits as apricots, plums, peaches, and all varieties of grapes. The lands of the Central irrigation district are upon an evenly surfaced plain, the general slope of which is from 5 to 10 feet to the mile, and is favorable to the distribution and application of water in irrigation. The average rainfall, mostly occurring in winter and early spring, amounts to about 15 inches.

The Sacramento river, from which the main canal receives its supply, reaches its flood heights in the spring, receding slowly in summer and not reaching its lowest stage until late in the fall. From December until June the depth of the river averages about 22 feet, after which it falls to 8 feet at the beginning of September and commences to rise again in November. Its drainage area above Collinsville is 26,187 square miles, and its maximum flood, which occurred in November, 1881, was 160,000 second-feet. Its mean annual discharge, however, is about 35,000 second-feet, and varies from a minimum discharge of 7,000 second-feet in late fall to an annual maximum discharge of about 80,000 second-feet occurring in the spring. During the period of years from 1878 to 1885, inclusive,[1] the average discharge during the irrigation season from February to July, inclusive, varied between 36,000 and 99,000 second-feet, the minimum discharge in this period being 14,500 second-feet. From these data it is evident that the discharge of the river is more than sufficient for the demands of the Central irrigation district.

The main canal, which has a capacity of 730 second-feet, heads on the west bank of the Sacramento river at a point near the extreme northern line of Glenn county. The Sacramento river is peculiarly adapted to the cheap diversion of water by means of moderate-sized canals. It has built up its bed and banks by the deposition of sediment in such a manner that the river practically flows on the crest of a ridge, its high-water mark averaging in the neighborhood of the Central irrigation district about 10 feet above the lowest lines of the valley. As a result of this it was found unnecessary to construct a weir or other obstruction in the river for the diversion of water into the head of the canal. A simple deep cut was made through the ridge on which the river flows and by this means a sufficient amount of water enters directly at the head of the canal to supply its relatively small demands.

The bed of the canal at its head is from 1 to 2 feet below low-water level, and in the canal at a little over a quarter of a mile from the entrance cut are constructed the regulating head gates. These are of brick masonry and as there is not much pressure they are easily raised and lowered by means of a simple contrivance. (Pl. CXXXI.) The method of neutralizing the pressure on the head gates is by a secondary set of regulating gates of timber constructed in the canal about 3 miles below the main gates. These secondary gates are built in the side of the earth cut and weighted down with earth, and opposite them is an escape cut leading the water back into the Sacramento river. These secondary gates are closed with simple flashboards, the total height of the gates being 24 feet above the grade of the canal; the main head gates having an equal height, necessitated by the height to which the Sacramento river rises in flood. By means of the flashboards placed in the secondary gates the water can be raised on the upper main head gates to a height equal to that in the river, thus removing the pressure on the head gates.

---

[1] William Hammond Hall, Physical Data and Statistics of California. Sacramento. 1886.

The main canal crosses the natural drainage of the country and in its course has to pass many small freshet streams and several comparatively large ones. The smaller streams are passed by means of level crossings, some with inlet gates on the upper side, and in all cases outlet escape gates in the opposite bank of the canal and regulating gates in the canal below the crossing. The object of constructing inlet gates is to prevent the backing of water up the stream, thus damaging property above it and necessitating the leveeing of its banks. Six miles below its head the canal crosses Stony creek at St. Johns. This is quite a large stream, the maximum discharge of which is as high as 20,000 second-feet.

The passage of Stony creek is effected by means of seven semicircular wooden culverts or inverted siphons. These are hung under a wooden platform, the top of which is level with the creek bed, while at the culvert crossing a cheap wooden apron and river training works are built in the bed of the creek. (Fig. 117.) A few miles below Stony creek it is proposed to take off two main branch canals, one following either side of the low depression or trough in the valley. These canals are for the supply of the Colusa irrigation district, which lies between the Central irrigation district and the Sacramento river at Willows. The Central district canal crosses Willow creek, and a little further on Logans creek, after which it has numerous small drainage lines to cross.

The total length of the main line as constructed is 60 miles. For the first 6 miles to Stony creek the average depth of the cut is 14½ feet, the canal reaching Stony creek at a grade level with its bed. The maximum depth of the cutting is 19 feet and as before stated the capacity of the canal at its head is 730 second-feet. At this point the bed width is 60 feet, depth of water 6 feet, grade ·0001 and slopes 1 to 1 in cuts, elsewhere 1 on 2 inside and 1 on 3 outside. The cross section of the canal is maintained as above for 20 miles to near Willows and is gradually reduced as distributaries are diverted to a minimum bed width of 25 feet at its termination. In addition to the first main escape at the third mile there is another escape at the eleventh mile into a slough which leads the water back into the Sacramento river. This canal may readily be increased in dimensions so as to irrigate all the land included in the Colusa district between the Central district and the river and may be prolonged to the southward for a great distance.

After crossing Stony creek the canal flows in a southwesterly direction past Willows, after which its direction is southerly and finally southeasterly to its termination at Cortina creek, into which it tails. As at present planned the Central district works will consist in all of 61·35 miles of main canal, 199 miles of distributaries and ditches varying in width from 8 to 20 feet on the bottom and carrying from 2 to 4 feet in depth of water. These distributaries are expected to transport the water to the highest point of each 640-acre tract of land.

The irrigation works of the Central irrigation district[1] are estimated to cost $940,364·25 of which about $294,785 had been paid out on July 1, 1891. This cost is distributed as follows:

Main canal, 3,347,000 cubic yards of excavation	$445,250
Distributaries, 779,980 cubic yards	54,598
Wooden ditches, flume, and culvert, respectively, across Stony creek, Calmes creek, and Old Story creek	56,254
Head works	28,254
Inlet and outlet level crossings	8,571
Regulators	5,354
Distributary heads, etc	8,386

The remainder for railway crossings, bridges, etc. One of the heaviest items of cost in connection with this work was the procurance of the right of way, $111,200 being required to purchase right of way for the main canal and $56,485 for the laterals.

BEAR RIVER CANAL.

The Upper Salt Lake valley in Utah contains a notable example of canal engineering in the works of the Bear River Canal Company. So far as can be ascertained, the first engineering work of importance done on this canal was by Mr. Fred Mathias, who was chief engineer during the making of the final location surveys and the earlier construction work. Mr. J. C. Ulrich was chief engineer for about a year, while during the past two years Mr. Fred Eitel has been chief engineer.

On this canal are several permanent structures of masonry and iron, though wood has been used in some instances to the detriment of the work and especially in the construction of the deep fills over side-hill ravines. There are several such fills as these on top of which the water of the canal is carried in a wooden flume. The leakage from the flume causes the rapid destruction of the fill and this will always add to the expense of maintenance unless an iron flume be substituted for the wooden one or the wooden flume be carried on a viaduct instead of on a fill.

The works of this company are intended to irrigate the northern half of Salt lake valley. (Fig. 75.) The projected canal system when completed will command 236,000 acres, most of which is excellent irrigable land, and for which a sufficient mileage of main canals and laterals have been projected to irrigate 200,000 acres. Wherever in the valley of the Bear river a scanty supply of water could be obtained from minor streams and springs the land has long since been occupied, and the results of farming are encouraging in the highest degree. The

---

[1] Central Irrigation District, California, William Hammond Hall, Bacon & Company, San Francisco, 1891.

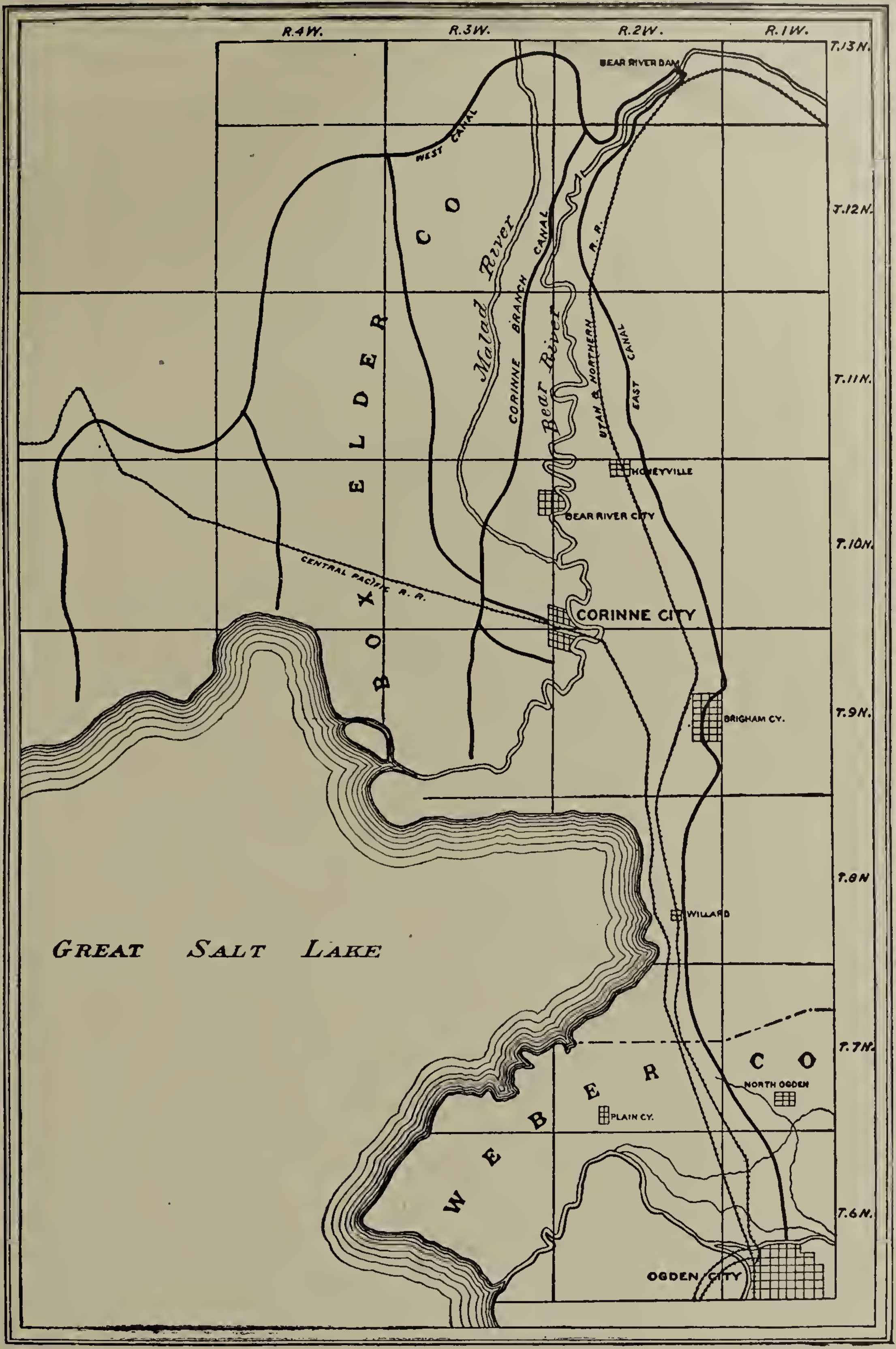


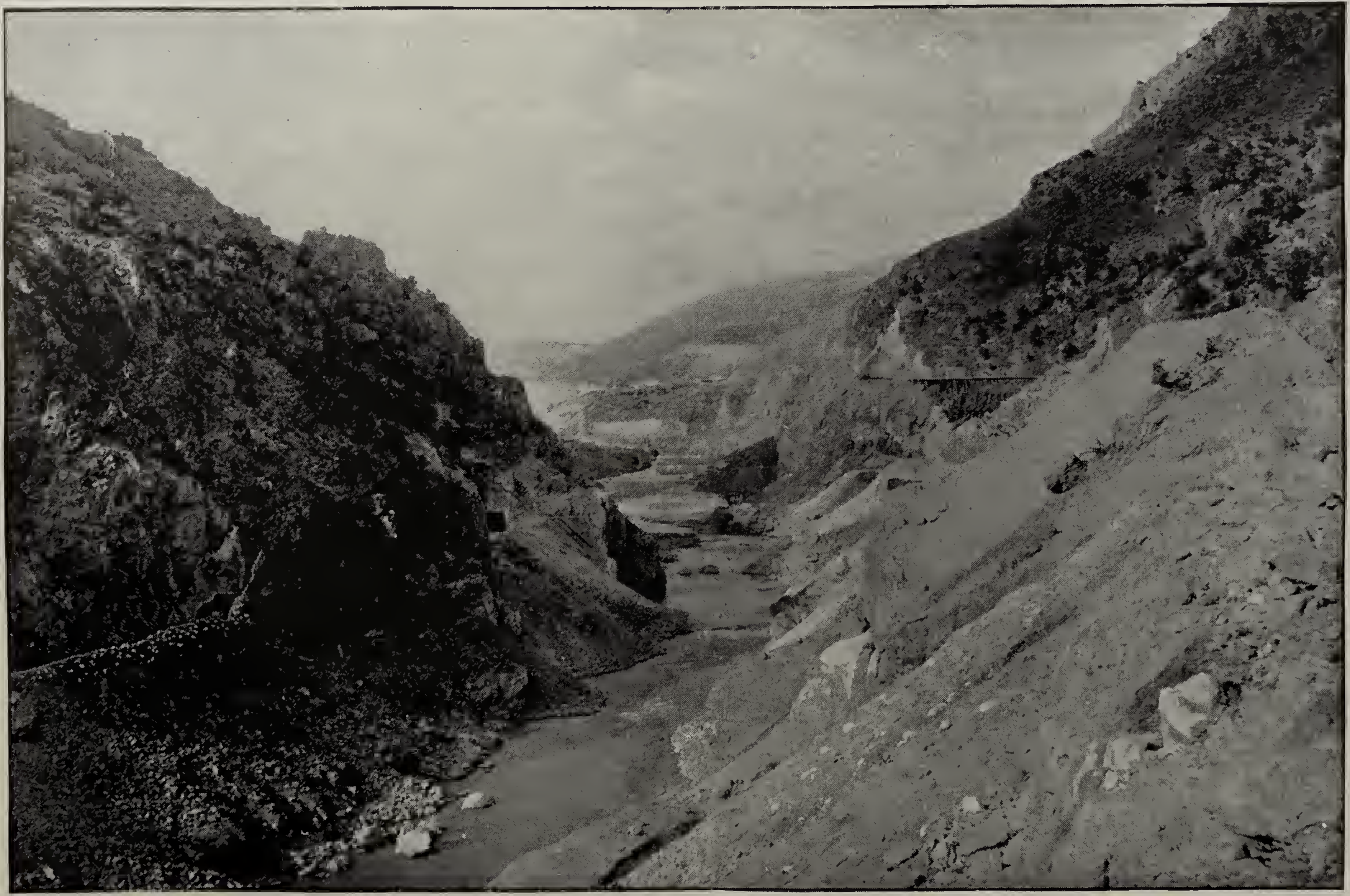
FIG. 75.—Bear river canal system.

uniformity of the surface slopes cheapens the construction of irrigating works and the watering of the land. The variety and diversity of products from this region is great, all forage grains and vegetables thriving well, while the fruits of the temperate zone can be produced in abundance.

The waters of Bear river are particularly well adapted for irrigation owing to their even temperature. The discharge of the stream is fairly uniform. In 1889, a season of abnormally low discharge in all the streams of the West, the minimum discharge was 360 second-feet and the mean discharge only 710 second-feet. In 1890, a year of fair average flow, the minimum discharge occurring in September was 1,300 second-feet; the maximum in May was 8,200 second-feet, and the mean of the year 3,000 second-feet. It will be seen from this, and from the capacity of the canal which is given later on, that the discharge of this river, especially toward the end of the irrigating season, is insufficient to fill the canals. As the flood discharge during a large portion of the year is high the perennial flow of the stream can readily be increased by means of water storage, the facilities for which are apparently fairly good, though further surveys and investigations will have to be made before their true value can be ascertained.

The Bear river canal is diverted from the Bear river at a point about 3½ miles above Colliston, where the river emerges from a rock canyon. The construction of a short and cheap diversion weir has enabled the company to bring water at comparatively little expense into the heads of both canals, though the first few miles of construction on these has been very expensive because of the rock work in the canyon. The Bear river canal system consists essentially of two main canals—the western and eastern canals—diverted one from either bank of the river by a common weir, while the western canal is divided again into three main branches, from which are taken the various laterals supplying private ditches. At present there are completed the diversion weir and the first 6 or 8 miles of heavy rock work in the canyon on both canals, thus bringing the water to the level of the broad valley lands which it is intended to irrigate. In addition, about 20 miles of the main western canal and some miles of the upper portion of the Corrine branch have been built, including several expensive flumes and other works. In all there are now finished about 60 miles of main canals with the regulators and head works and a few miles of distributaries. The system contemplates the construction of 150 miles of main line and principal distributaries and a large mileage of laterals. Nearly $2,000,000 have already been spent on this work, while its total cost is estimated to be $3,000,000.

The diversion weir for this canal, which is shown in Pl. CXXIII, is admirably located between high rock abutments with a shallow rock foundation. It is constructed of wooden crib work filled with rock and earth and has a total height of 16½ feet and a width at the bottom



BEAR RIVER CANAL IN CANYON.

parallel to the channel of the stream of 38 feet, its length between abutments being 370 feet on the crest. The first two miles of the east side canal are in heavy rock work, in which are two tunnels about 14 by 14 feet cross section in homogeneous rock and unlined, the first being 423 feet long and the second 200 feet in length. In this portion of the canal are a number of deep rock cuts (Pl. CXVI), the greatest of which is 96 feet in height on the upper side, while in numerous places the lower side of the canal consists of a built-up retaining wall of rubble masonry in cement, usualy 10 feet in height inside, with a top width of 2½ feet, and a width at grade line of 7½ feet. (Fig. 76.) For 5 miles below the rock work the canal is excavated in steep earth hillsides the slope of which is about 3 to 1. In this portion of the line are several deep fills across ravines the beds of which are drained by means of drainage culverts carried through the bank. The greatest fill is 108 feet in depth at the center and 500 feet long on grade and on the top of this is laid a wooden flume which carries the canal water and rests on long piling driven 60 feet into the fill. There are several such fills as this on both of the main canals, and two or three of them have already been washed out owing to leakage from the flume or insufficient drainage way through the embankment. After reaching the level country the east side canal has a bottom width of 50 feet, a depth of water of 7 feet, with side slopes of 1 to 1 and a grade of 1 foot per mile. This canal as projected will have a length of 50 miles, terminating at the Ogden river in the city of Ogden.

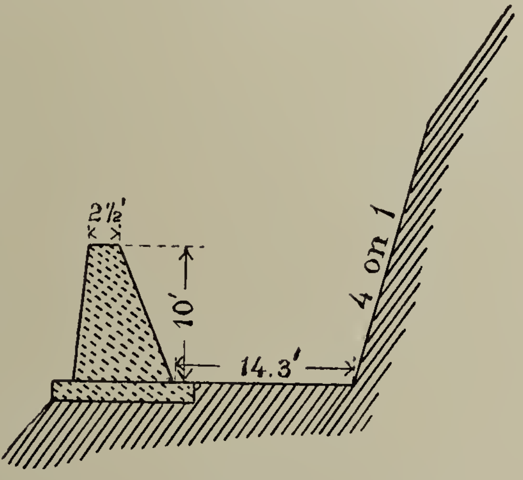


FIG. 76.—Bear river canal. Cross section of hillside work.

The west side canal for the first 9,000 feet of its length is likewise constructed in heavy rock canyon work. In this portion of its line are six tunnels, varying in length from 57 to 279 feet and having the same cross section and grade as the east side tunnels. Below and between the tunnels are eleven big retaining walls of rubble masonry, having dimensions similar to those on the east side canal; while this portion of the canal has a bed width of 14·3 feet, a depth of 10 feet, and nearly vertical slopes through rock work. Twelve hundred feet below the head of this canal is an escape gate and 600 feet farther down is a second escape gate, both discharging back into Bear river and both having clear discharge openings of 12 feet in width, closed by three wooden gates, sliding between iron posts set in masonry piers. Below the second escape is a regulator closed by five gates each 4 feet in width, by which the discharge in the canal itself can be controlled. After leaving the rock work the canal enters steep hillside excavation in earth and clay similar to that on the east side and extending to the sixth mile. In this side hill work the bottom width of the canal is 143 feet, depth 12 feet, side slopes approximately 1 to 1, while there are several deep fills and cuts similar to those described for the east side. Beyond the ninth mile the canal crosses Malad river and valley on a high iron bridge and flume, 378 feet in length and 80 feet in maximum height, supported on iron trestles, the river span of which is 70 feet.

Six miles below the head of the west side canal the Corinne branch is diverted, which terminates in the twentieth mile of its course at the city of that name. This branch at its head is 22 feet wide at the bottom and carries 10 feet depth of water (Fig. 77) and is controlled at its head by a double set of regulating gates. In the main and Corinne branches the bottom and sides of the canal are well protected by wooden aprons and wings. As this branch runs down the slope of the country it has in its course sixteen vertical falls varying from 4 to 12 feet in height, one of which is illustrated in Fig. 104. At the fourteenth mile Malad river is crossed on a high iron bridge founded on piles resting on iron cylinders filled with concrete. This bridge (Fig. 114) consists of three principal bents from 25 to 60 feet in length, the peculiarity of its construction being that the superstructure forming the bridge itself is of iron plate girders and constitutes the flume which carries the water. Among other works on this canal are some inverted siphons or culverts made of wood for carrying distributaries under the larger canals.

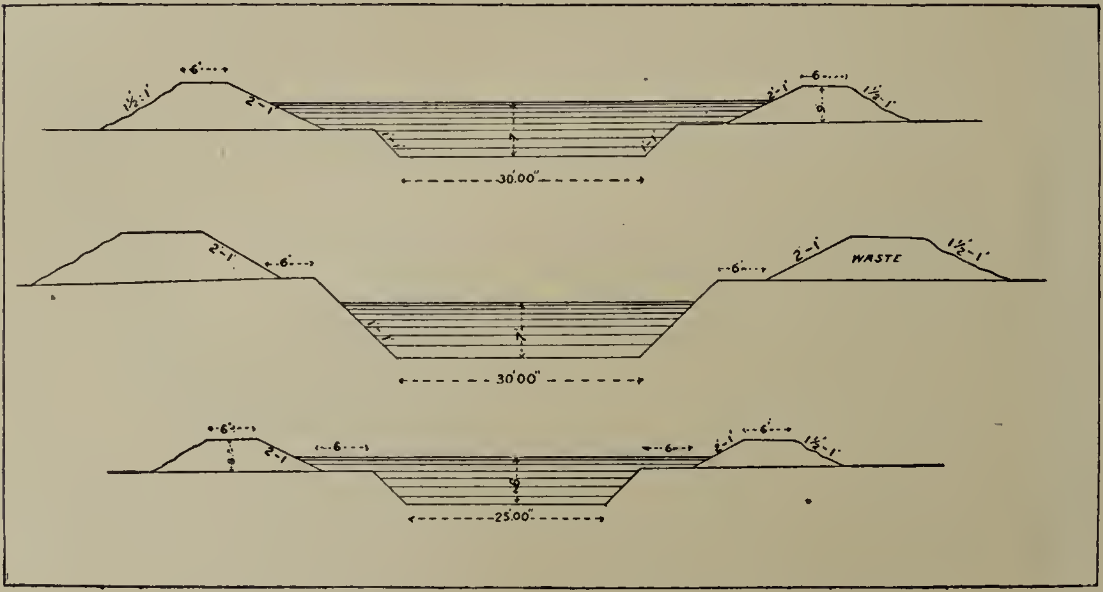
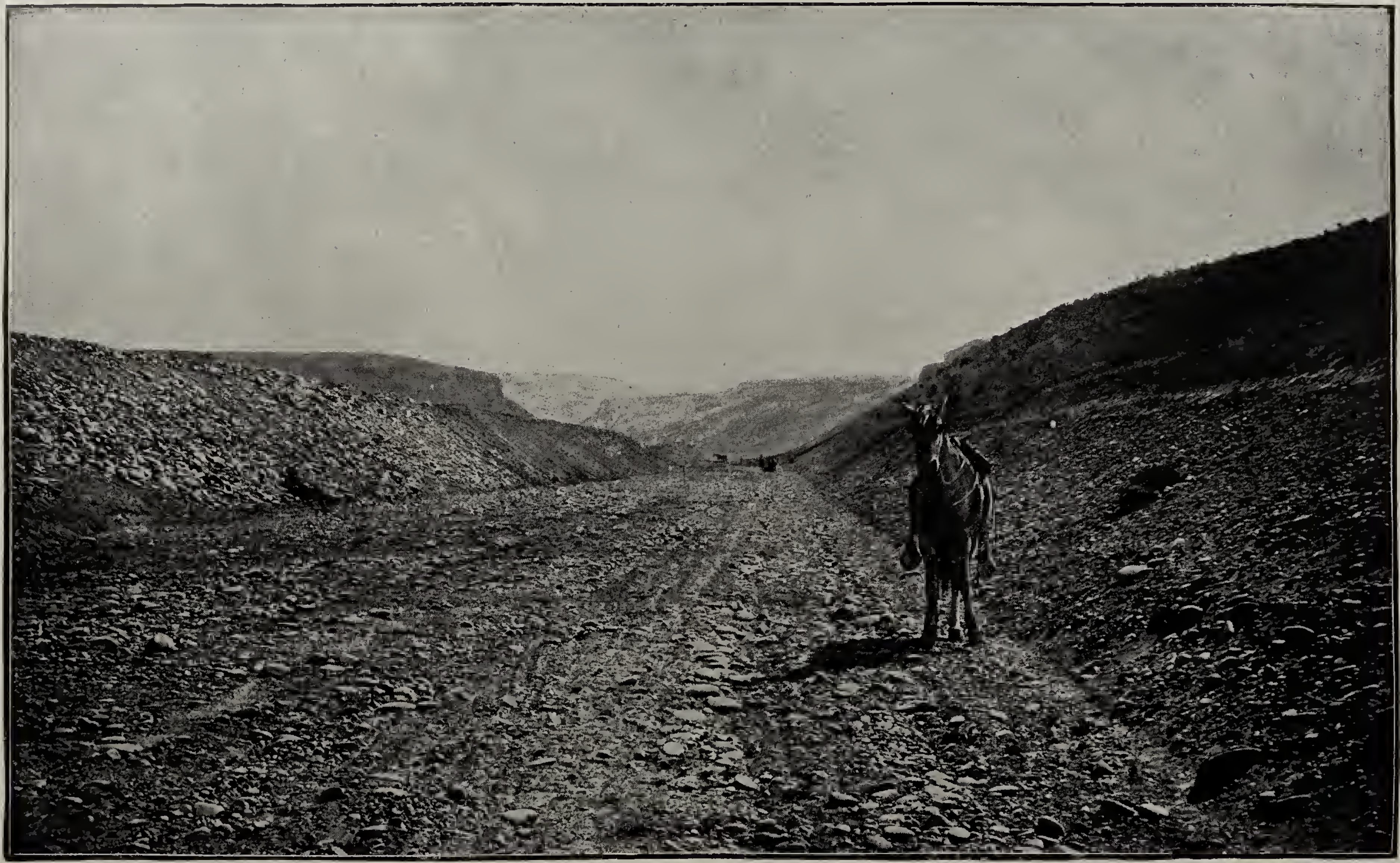


FIG. 77.—Bear river canal. Cross sections of Corinne branch canal.

IDAHO MINING AND IRRIGATING COMPANY'S CANAL.

The magnificent canal which is being constructed near Boise, Idaho, under the above name is diverted from the Boise river about 12 miles above the city of Boise. This canal is interesting, not because it encounters any serious difficulties in construction, but because of the



VIEW OF IDAHO CANAL DURING CONSTRUCTION.

careful and intelligent thought which has been displayed by its engineer, Mr. A. D. Foote, in every detail of its design, and because of the magnitude and permanent character of the various works constructed upon it.

The lands which will be irrigated by this canal are situated in the southern part of Ada county in Idaho between the Snake and Boise rivers. They lie in the form of a triangle (Fig. 78), two sides of which are formed by the Snake and Boise rivers, the other being formed by the line of the main and eastern branches of the canal. This triangle measures about 60 miles on each side and contains approximately 400,000 acres of land, about 350,000 acres of which are irrigable from the canal. The land lies in two great plains, separated by a high ridge running nearly parallel to the Snake river and dividing them into two unequal portions, the larger of which slopes toward the Boise and the smaller toward the Snake river. In addition to the irrigable lands commanded by this canal, there is a large body of auriferous gravel lying along the Snake and Boise rivers near their confluence. One of the purposes of the company is to utilize the surplus water carried by the canal which terminates near these placer deposits in mining them by the hydraulic process. The climate and soil of this region are such that abundant crops of the more valuable grains, vegetables, and temperate zone fruits can be grown.

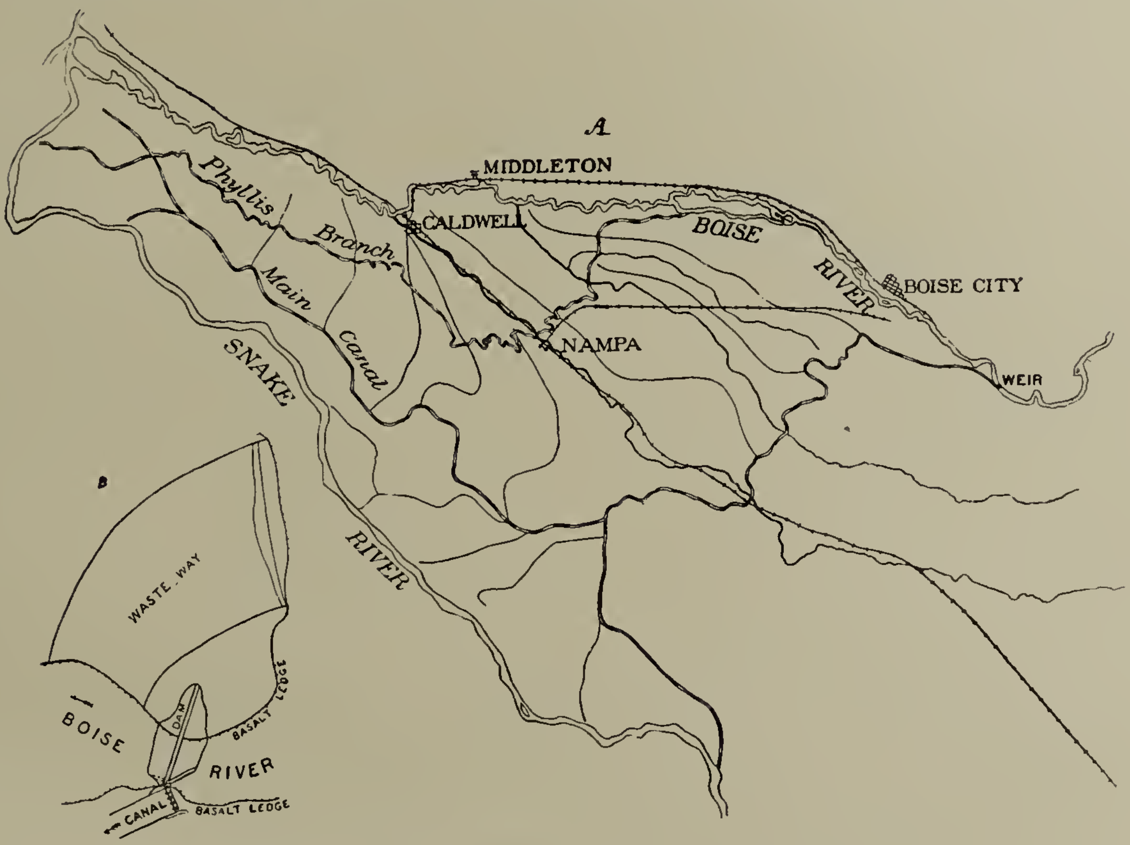


FIG. 78.—Idaho canal system, A. and plan of headworks, B.

The Boise river, heading in the Saw Tooth mountains of central Idaho, has a catchment basin of about 2,500 square miles. From measurements of the discharge of this stream made during a period of four years[1] it appears that the discharge is lowest between September and March, when it varies between 1,200 and 2,000 second-feet. From then on through the spring and summer irrigating months the discharge increases to a maximum of 30,000 second-feet. It will accordingly be seen that the discharge of the river will, with the exception of the months of July and August, be sufficient to fill the canal. With the addition of a few storage reservoirs, however, a sufficient supply to fill the canal would always be assured. Five reservoir sites have been discovered on the headwaters of the Boise river, the capacities of which vary between 7,000 and 155,000 acre-feet. The maximum discharge of the main canal is about 2,500 second-feet.

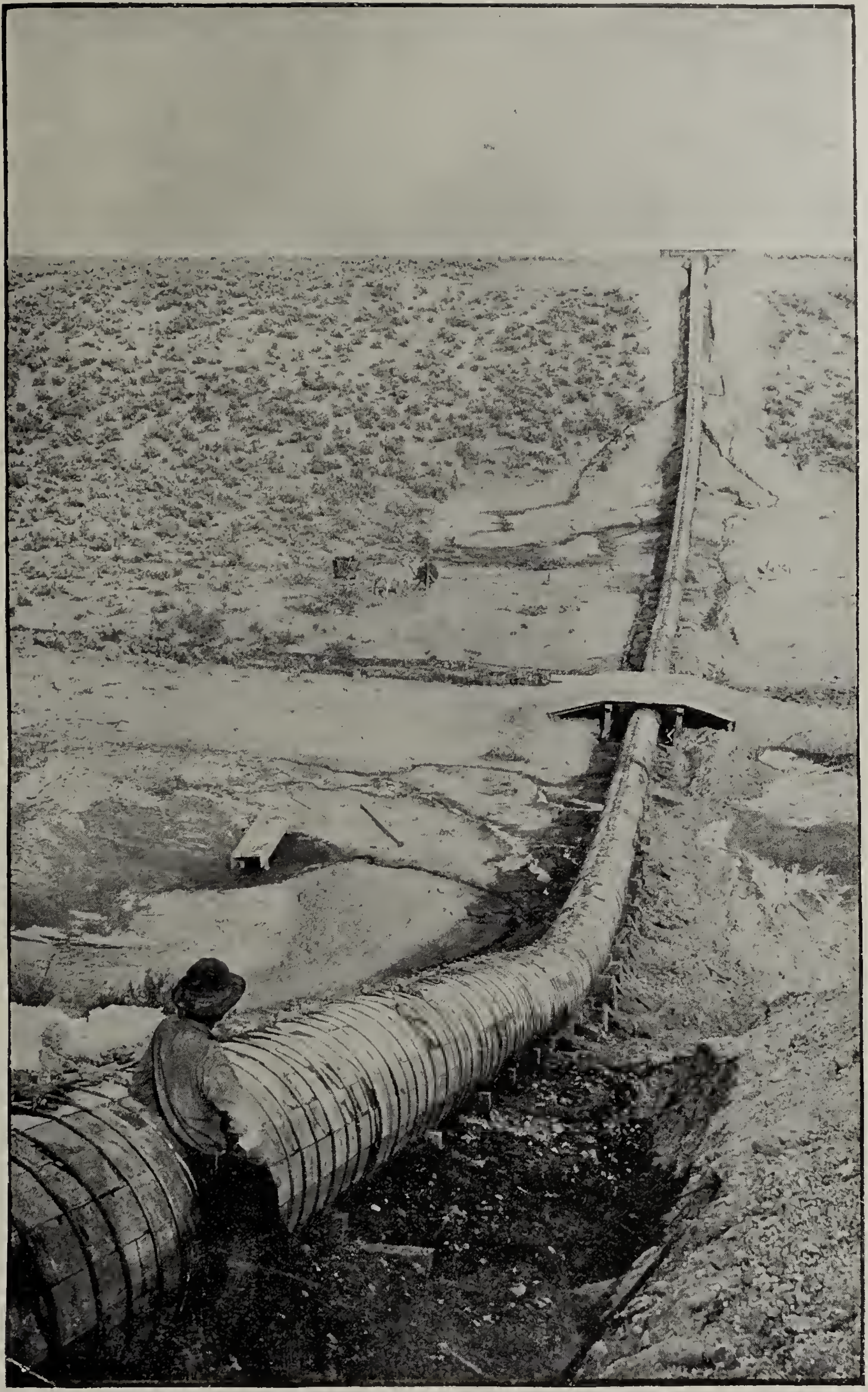
The lands covered by this canal system have an excellent natural drainage. The channels of Indian, Tenmile, Black, and other creeks which drain it are cut deep into the lava which underlies it, thus rendering the streams harmless while giving them all the conditions for properly draining the adjacent country. The soil of which these lands are composed is of a most productive quality, and consists of a decomposed lava underlain by gravels.

The point selected for the dam and head works of the canal is in a gorge surrounded by high precipitous lava banks, between the walls of which the river emerges from the mountains onto the level Snake river plains. The walls of the canyon are immense gravel banks capped with and resting on basalt, which at this point forms the river bed. In the lower stratum of this material the river has worn a channel a few feet deep, which enabled the engineer to construct the head gates and wasteweir on opposite sides of the river upon solid rock foundations. The diversion dam at the head of the canal is particularly well located, as shown in the accompanying illustration. (Fig. 78, B.) It consists of two parts, a main dam of loose rock with earth filling on its upper side, which is thrown across the channel of the river, and over which it is not designed that the flood waters shall pass, and a wasteweir excavated through gravel on the north side of the river, at a point about 345 feet above the dam, in which is built a masonry weir for the flood waters to flow over. Just above the dam a basalt ledge, 12 feet in height, borders the river bank. On this is constructed the wasteweir, the average width of which is about 450 feet. The crest of the weir in this wasteweir is 8 feet below the crest of the dam, and the length of the wasteweir is 720 feet from its entrance to the point at which it discharges into the river below the dam, while its capacity is estimated to be about 30,000 second-feet, equal to that of the highest recorded flood.

The canal heads on the south bank of the river immediately adjacent to the end of the dam, in which latter is constructed an under or scouring sluice, the object of which is to prevent the deposition of silt in

---

[1] A. D. Foote, Report on Irrigation and Reclaiming Desert Lands in Idaho. Boise, Idaho, 1887.



PHYLLIS CANAL PIPE LINE.

front of the head gates of the canal. These gates rest on the summit of a basalt ledge similar to that described as bordering the northern bank of the river and of equal height. The gates are constructed of the best rubble-in-cement masonry, and are covered on top, forming an overhead bridge 10 feet in width. The regulating gates are 8 feet wide in the clear, and 10 feet in height to the crown of the semicircular arch. The total height of these head gates above the basalt ledge is 21 feet, and their height above the river bed 33 feet. (Fig. 95.) The head gates will be closed by means of roller curtains made of steel plates and angle iron for a height of 10 feet above the sill, above which the slats of the curtain are made of pine wood, each slat 6 inches wide. (Fig. 99.)

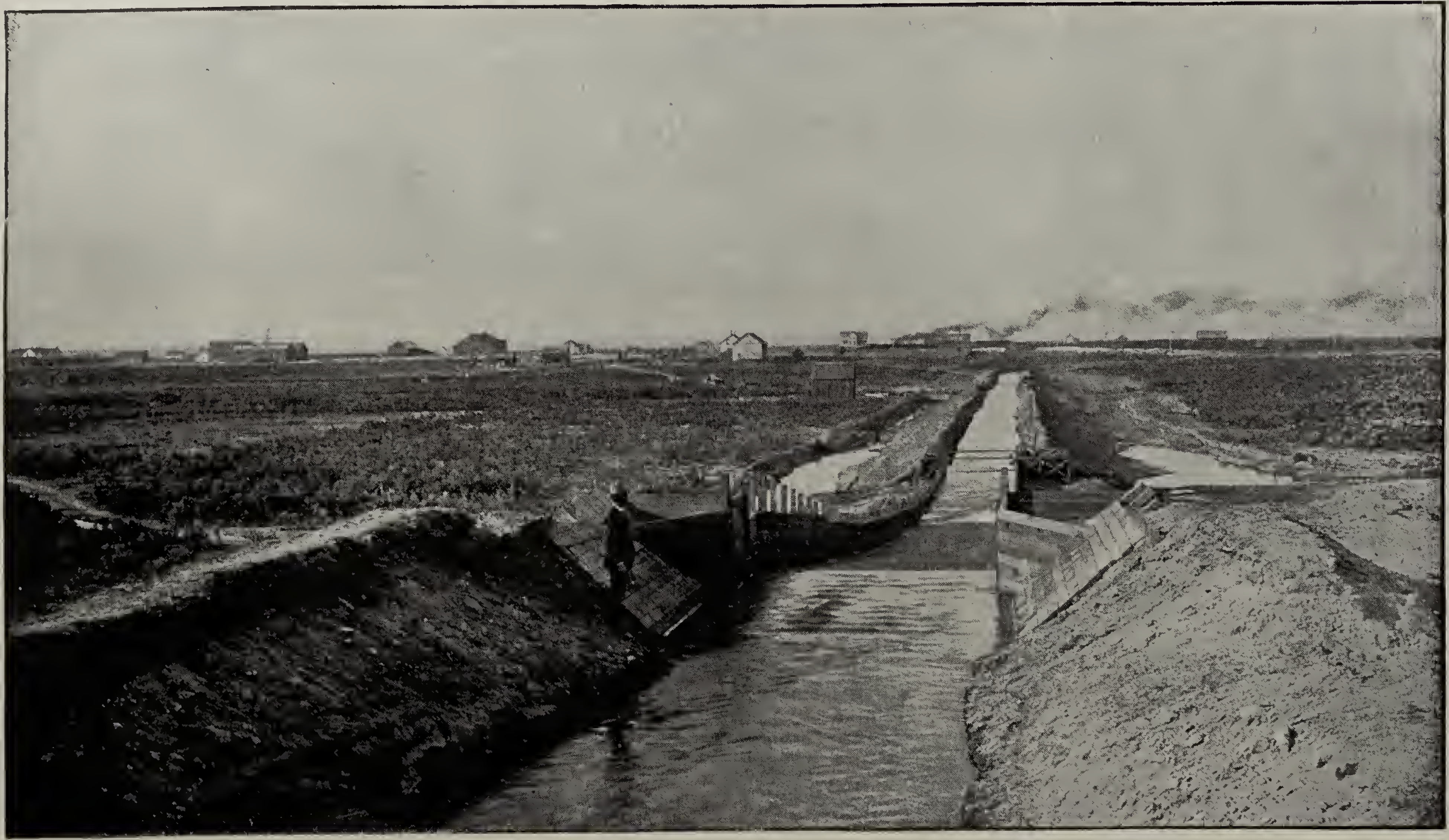
The first 2 miles of the main canal are excavated in loose lava rock in the steeply sloping sides of the canyon, the inclination of which is in places nearly 25 degrees from the horizontal. There are no bad cuts or fills encountered in this canyon work, and below it the canal encounters a couple of rather steep gravelly bluffs which its grade has to surmount before it reaches the main body of the irrigable land. These lands are reached in about the eighth mile, after which the work is in simple level earth excavation and encounters no other difficulties than three short stream crossings; one at the fifteenth mile, where Fivemile creek is crossed by means of a short terre-plaine or raised embankment, with a wooden flume of about 24 feet in length founded on piles across the channel of the stream (Fig. 112); there are two similar crossings at Tenmile and Indian creeks. In the first 8 miles of gravel bluff work below the canyon the canal is constructed one-half in excavation and one-half in fill, the lower side being a higher embankment which is well tramped over and constructed with scraper. In one place this embankment is over 40 feet in height for a length of about 1,000 feet, which is practically an earth dam for this distance. (Pl. CXVII.)

The capacity of the main canal is estimated at 2,585 second-feet; its bed width is 40 feet; height of bank 12½ feet; the depth of water, 10 feet, and velocity of current, owing to its construction in the gravel and rock, as high as 5 feet per second. The main canal and its branches have varying cross sections, their capacities diminishing as the distance from the head increases, since the volume of water to be carried diminishes owing to its diversion by distributaries. Thus, while the capacity near the head of the canal is 2,585 second-feet, beyond Tenmile creek it is reduced to 1,925 second-feet, and before its bifurcation at the thirty-fourth mile its capacity is 1,540 second-feet. The eastern branch has a capacity of 420 second-feet and the main or western branch 1,120 second-feet. After getting above the bluffs to the level, open country, all slopes to banks, both in and outside, are 1 on 1½, and a uniform grade of 2 feet per mile is given. The main canal has a total length of 70 miles, and tails into the Snake river at the placer mines above mentioned. At the thirty-fourth mile of its course the main eastern branch is diverted, which is 15 miles in length and likewise terminates in the Snake river.

On the main line at the end of the canyon is an escape for the discharge of surplus water which tails back into the Boise river. This escape (Fig. 101) consists of a number of 48-inch cement pipes laid through the canal bank and closed on the inner or water face by a sloping wooden gate laid at the angle of the canal banks and operated from above by rack and pinon. All distributary heads are constructed in the same manner—concrete pipes laid through the canal bank. In addition to the first escape below the canyon, provision is made for wasting water from the flumes crossing Fivemile, Tenmile and Indian creeks into those streams. On the main line just below the bifurcation of the eastern branch is a fall 49 feet in height; about 6 miles further on is a 12-foot fall or drop, and further on, on the same line, are a 22-foot and 28-foot fall. These are not true falls, but are chutes or rapids constructed at such points as to take advantage of rock which crops out near the surface, and in which they are excavated, other portions of the rapids being masonry lined. All similar drops on the minor branches consist of inclined wooden flumes or rapids, laid on slopes of from 1 to 5 feet in 100.

Previous to commencing the construction of the main canal the Idaho Mining Company built a secondary line called the Phyllis canal, the object of which was to reach the placer mines by the shortest route and in the least space of time, so that some return might be derived from these while waiting the construction of the main line and also in order that the canal might develop irrigation farms along its line. The Phyllis canal now heads at a point 22 miles below the main line and is diverted by means of a simple cut from the river. It is intended, however, that as soon as the main line is completed the Phyllis line shall be fed by means of a cross-cut from the main line.

The Phyllis canal skirts the river for about 6 miles before it reaches the summit of the bluffs, after which it crosses the country in a comparatively direct line to the town of Nampa, whence it flows down the slope of the interfluve between the Snake and Boise rivers to the mines on the former. Its total length is 54 miles; at its head its bottom width is 12 feet, slopes $1\frac{1}{4}$ to 1, depth of water 5 feet, while its grade is 2 feet per mile, and its capacity 250 second-feet. It covers about 50,000 acres of land. On its line are two or three works of interest, the most noteworthy of which is a long wooden pipe line by which its waters are carried across a deep depression. This pipe line (Pl. CXVIII) is formed of staves or planks and is somewhat similar to an elongated barrel bound together by round iron hoops tightened by means of nuts and screws. The pipe rests on wooden trestles or supports sunk into the earth. There are numerous drops on this canal, the object of which is to reduce the grade, and these are in every instance made by means of rapids, not vertical falls. These rapids (Pl. CXIX) are practically inclined flumes



PHYLLIS CANAL RAPID.

of wood and have proven most efficient, the wooden lining to the canal preventing the erosion of its banks and the work being kept up with little cost for maintenance.

One feature of the distributive system of the main canal which is open to criticism is found in the natural drainage courses which are largely utilized as main distributing channels. (Fig. 78, A.) It is seldom that circumstances will allow the use of natural drainage channels for irrigation, but Mr. Foote believes that in this case they are perfectly adapted to the purpose with the additional advantage of being inexpensive and absolutely safe from breakage. The first important distributary taken off from the main canal is Fivemile creek, where a waste weir is being constructed and head gates put in, the creek itself being used as the distributary. The fall of this stream is 20 feet to the mile and it is intended that small weirs and gates shall be placed in it about a mile apart at which lateral ditches will head and convey the water to each farm. These laterals which are taken from the various creeks or main distributaries become the supply channels for the land below them while at the same time they receive the drainage from the land above. The channel of Indian creek being narrow and deep-set in the rock is not available for use as a drainage canal except in its lower portion.

TURLOCK CANAL.

The Turlock district is so outlined that all of the 176,110 acres included within its borders can be watered from the same source of supply. It is situated in Merced county, California, and was the first district organized under the provisions of the Wright act. It is, therefore, of particular interest from a legislative point of view. In addition to this fact, it enjoys the distinction of possessing the most interesting and magnificent canal in this country, because of the character and excellence of its work and the skill displayed by its engineer, Mr. E. H. Barton, in overcoming the difficulties encountered in locating the first few miles of its diversion line. (Fig. 79.)

The district was organized early in 1887, and preliminary plans and estimates were ordered and completed by George E. Manuel, civil engineer, in September of the same year. The preliminary estimates of cost rendered by Mr. Manuel was $467,500, and bonds were issued to the value of $600,000 in the following month. The final plans and estimates were made in October, 1889, by Mr. Eugene H. Barton, chief engineer, which very materially changed the location and plans submitted by Mr. Manuel, and work was commenced in January, 1890. As a result of more detailed surveys, and the adoption of more substantial and permanent plans for the various works on the canal it is estimated that the final cost of the entire system will be about $1,110,000, including the cost of the great diversion dam, which is common to both the Modesto and Turlock districts.

The canal is diverted from the Tuolumne river at a point about 2 miles above the town of La Grange. This river rises among the higher peaks of the Sierras, and is fed from the snow which crowns their summits. The area of its catchment basin is about 1,400 square miles. Its discharge varies during the irrigating months from about 1,000 second-feet in April to a maximum of 20,000 second-feet in June, and falls to a few hundred second-feet in July and the remaining summer and fall months. The total discharge, however, for the entire year averages about 2,000,000 acre-feet, so that providing the perennial water supply of the river is found insufficent for this and the Modesto district there will remain an ample volume available for storage. It is fortunate that reservoir sites on the head waters of the Tuolumne are both numerous and excellent, as shown by the surveys of the engineers of the U. S. Geological Survey, for several excellent sites, notably the Tuolumne meadows and Lake Tenaiya, were surveyed and found to have storage capacities ranging from 23,000 to 45,000 acre-feet.

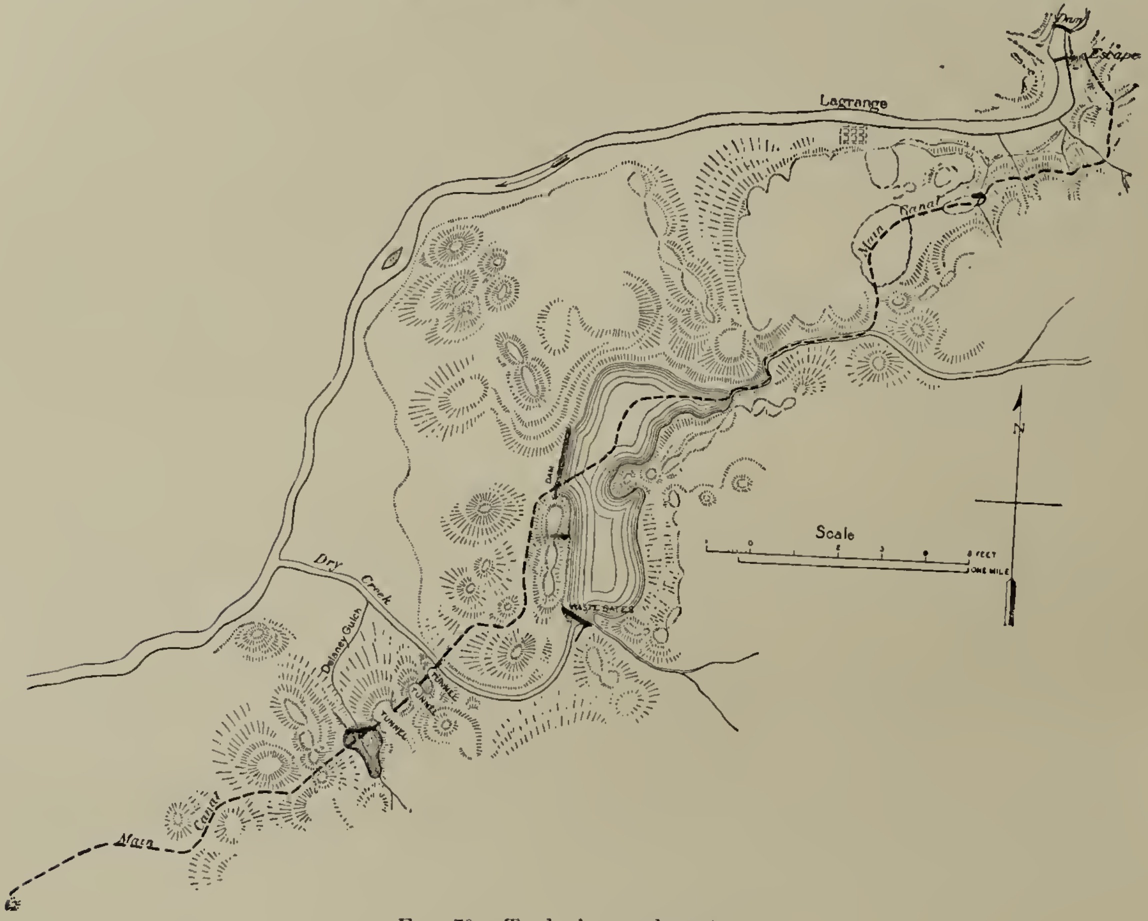


FIG. 79.—Turlock canal system.

The lands included within the Turlock district are of excellent quality for agricultural purposes and vary from the level valley lands, the soil of which is heavy black loam, to the gentle rolling and well drained foothill lands found at the upper end of the district, which soil is an excellent sandy loam and well suited to the cultivation of all the temperate zone fruits.

The head works of the Turlock canal consist of a masonry dam, which is constructed as a common diversion weir for the Turlock canal and the canal of the Modesto irrigation district, which latter heads on the opposite or north bank of the river. This weir is located between high canyon walls 2 miles above the town of La Grange, at a point where the abutments and foundation of the weir are on a firm, homogeneous, dioritic basalt, in which scarcely any excavation is required. The weir, over which the flood discharges of the river will pass, is constructed throughout of uncoursed rubble masonary in Portland cement, and has a length on its crest of 310 feet. Its maximum height, including foundations, is 103 feet, and the maximum height of the overfall of waters is 98 feet to a water cushion, formed by a subsidiary weir, built of rubble masonry and located at a point 200 feet below the main weir, in a narrow portion of the canyon. (Fig. 80.) The arrangement of the head gates of the canal is peculiar. The canal is diverted from the south bank of the canyon at a point about 50 feet above the end of the main weir. Owing to the great floods which occur in this narrow canyon, the water may rise as much as 15 feet in an hour, and the maximum height which it is estimated to reach above the sill of the canal is 16 feet. The pressure of this height of water on the regulator head would be great and would increase the cost of its construction accordingly. The canal heads in a tunnel 560 feet in length, blasted through the rock of the canyon walls and having no regulating apparatus at its entrance. Where it discharges into the open cut, which is the commencement of the canal, regulating gates and scouring or escape sluices

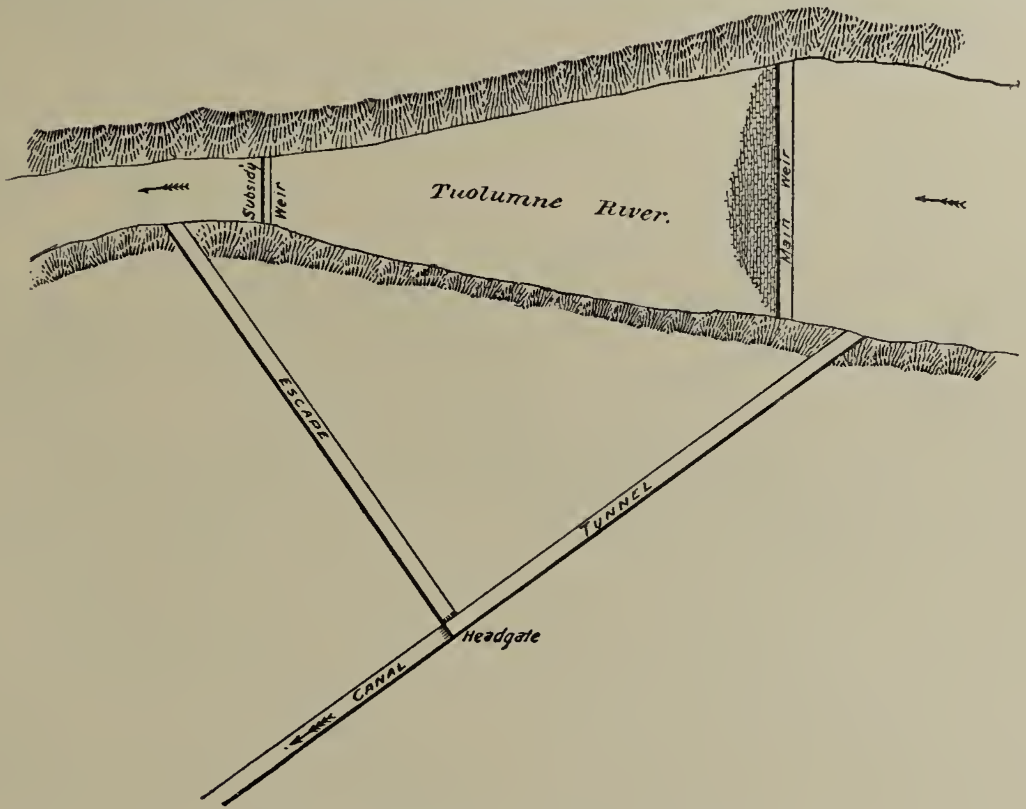


FIG. 80.—Turlock canal. Plan of headworks.

are placed. (Fig. 80.) The entrance tunnel is 12 feet wide at the bottom, 5 feet in height to the spring of the arch, above which it is semicircular with a 6-foot radius. Its slope is 24 feet per mile, and it is excavated in a firm dioritic rock, which requires no lining. The regulators in the canal-head below the exit of the tunnel consist of six gates, each 3 feet wide in the clear and 12 feet in height. These gates are constructed of timber and iron, and slide on angle iron bearings let into the rock and firmly set in concrete. The escape is set at right angles to the canal line, heading immediately above the regulator between it and the end of the tunnel and tailing back into the Tuolumne river a short distance below the subsidiary weir. Like the regulator, the escape consists of six gates, each 3 feet wide in the clear, 12 feet high, and constructed of similar material and in like manner. It is estimated that whereas a maximum flood of 16 feet over the sill of the tunnel will give a discharge in front of the regulator and escape of about 4,000 second-feet with a velocity of 20 feet per second, the wasting capacity of the escape will be at least 6,000 second-feet, thus fully insuring the canal against accident from this source.

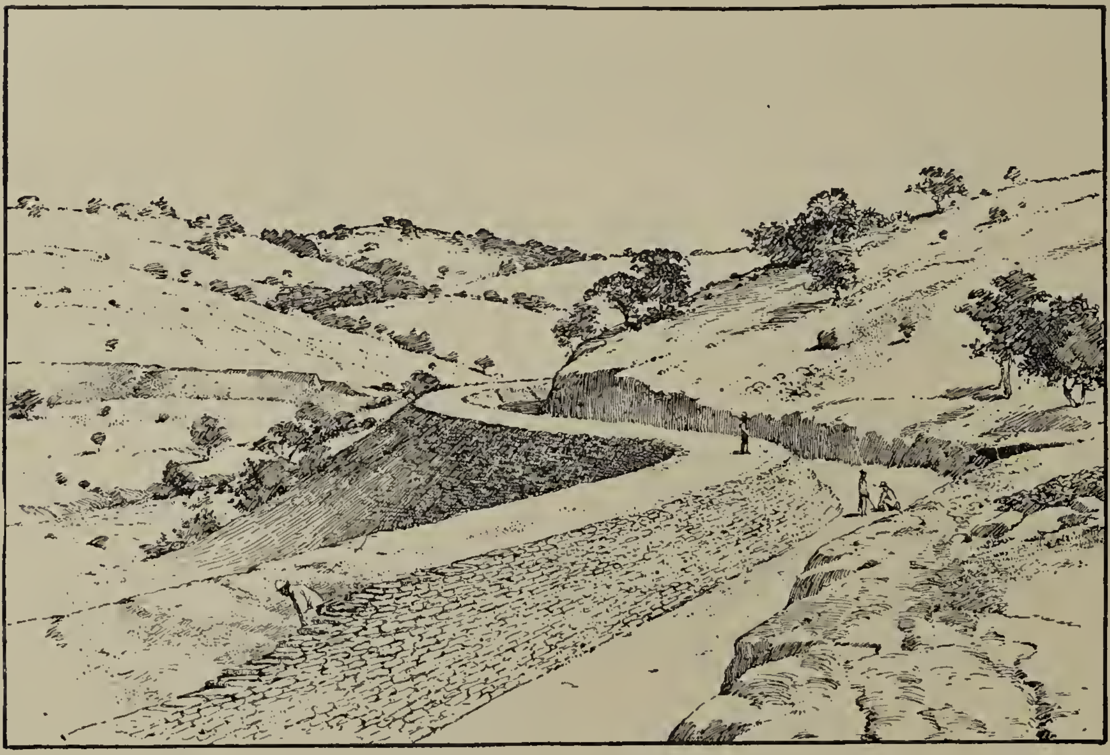


FIG. 81.—Turlock canal. View of sidehill work.

Below the regulating gates the main canal proper begins, having a capacity of 1,500 second-feet. For the first 6,200 feet it is excavated in slate rock on a steep hillside. (Fig. 81.) It has a bed width of 20 feet, depth of water 10 feet, the upper rock slope being 2 on 1, while the lower bank or down-hill slope, where gullies are crossed, is built up with an inner slope of 2 on 1, and faced with 18 inches of dry-laid retaining wall inside and outside, the interior of the bank consisting of a well puddled earth core of 12 feet in width. (Fig. 82.) Where this portion of the canal is on ordinary sloping ground, not crossing gulches, its dimensions are the same, but the inner face only has the 18 inches of riprapping, the down-hill slope of the bank consisting of dirt and other soil, the top width of the bank in such places being 5 feet and the puddle wall 5 feet in thickness. This portion of the canal line has a grade of 7·92 feet per mile, which gives a velocity of 7·3 feet per second.

At the end of this slate rock work the canal empties into Snake ravine, just above its junction with the Tuolumne river, up which ravine the water of the canal runs for 940 feet. This is effected by constructing an earth dam across the mouth of the ravine just below the entrance of the canal, which raises the surface of the water so as to form a small settling reservoir and produces a flow up the course of the ravine for the distance above mentioned. The earth dam is 20 feet wide on top, 318 feet long on the crest, with slopes of 1 on 2, and a maximum height of 52 feet. This dam was partly constructed of material borrowed from its abutments and the canal excavation, and partly by a silting process from material washed out of a hydraulic cut at the upper end of the ravine. This hydraulic cut is 800 feet in length and 45 feet in maximum height, with slopes of 1 to 1, and a grade of 5 feet per mile. Owing to the abundance of water procurable, this cut was more cheaply excavated by the hydraulic process than it could have been by other means. At the far end of this cut the canal water enters an old hydraulic wash, in which its waters spread out and which is utilized for its channel for a length of 2,380 feet, after which it enters a rock cut 860 feet long, with a maximum depth of 45 feet and a similar cross section to that of the cut first described.

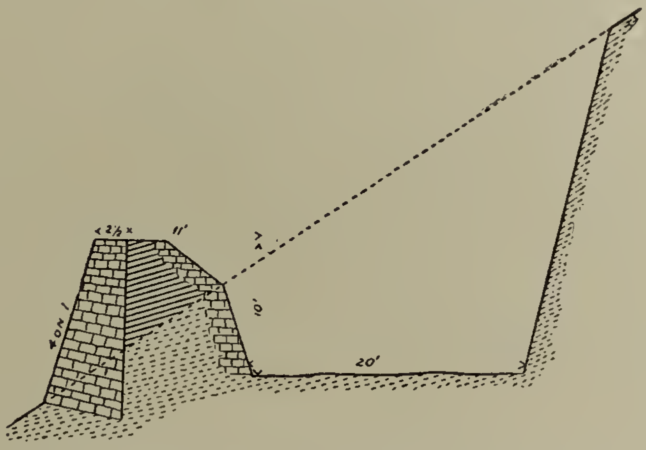


FIG. 82.—Turlock canal. Cross section of sidehill work.

At the end of this rock cut the canal water is discharged into Dry creek, down which it flows for a distance of 6,500 feet on a grade of 12 feet to the mile, and from which it is diverted by means of an earth dam 460 feet long. This dam has a maximum height of 23 feet with both slopes of 3 to 1, and is riprapped to a depth of 3 feet on its upper face. At the south end of the dam it abuts on sandstone rock, in which a waste way is cut 50 feet wide, with its sill 4 feet below the crest of the dam, and which will discharge back into the creek 180 feet below the toe of the dam. (Fig. 110.) Between the waste way and the end of the dam is a waste gate which it is intended shall be used in time of freshets, for Dry creek has a maximum discharge of 4,000 second-feet, and as the freshets are quick and violent a large wasting capacity is necessary. These waste gates are ten in number, each 3 feet wide in the clear and 10 feet in depth. They fall automatically outward or down stream, being hinged at the bottom to a concrete floor laid on the bed rock, and when raised they are attached by chains to the piers.

From Dry creek the canal is excavated for about a mile in heavy, sandy loam, in which it has a bed width of 30 feet, with slopes of 1 on 2, a depth of 10 feet, and a grade of 1½ feet per mile. At the end of this excavation the canal crosses Dry creek again in a flume 62 feet in height and 450 feet long, after crossing which the canal enters a series of three tunnels, the cross sections of which are nearly similar to that of the first tunnel, while they are excavated in a tufa and sandstone which will require no timbering. The first tunnel (Fig. 83) is 211 feet in length, the second 400 feet, and the third 400 feet in length, while they are separated by short, open cuts, excavated in hardpan and clay, which are, respectively, 250 and 300 feet in length. The last tunnel discharges into Delaney gulch, which is crossed by constructing a high bank or

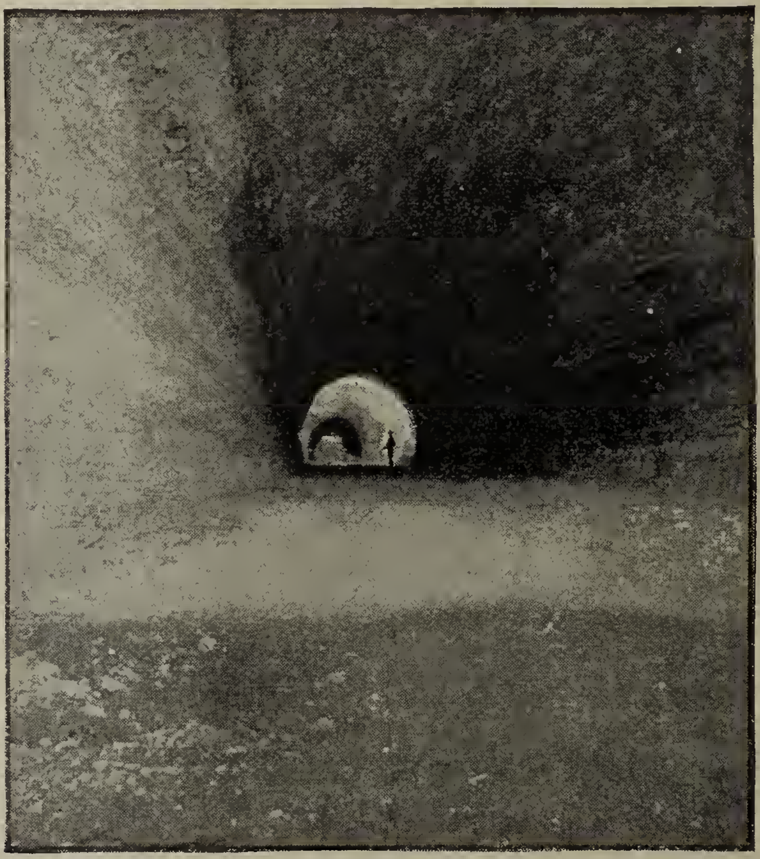
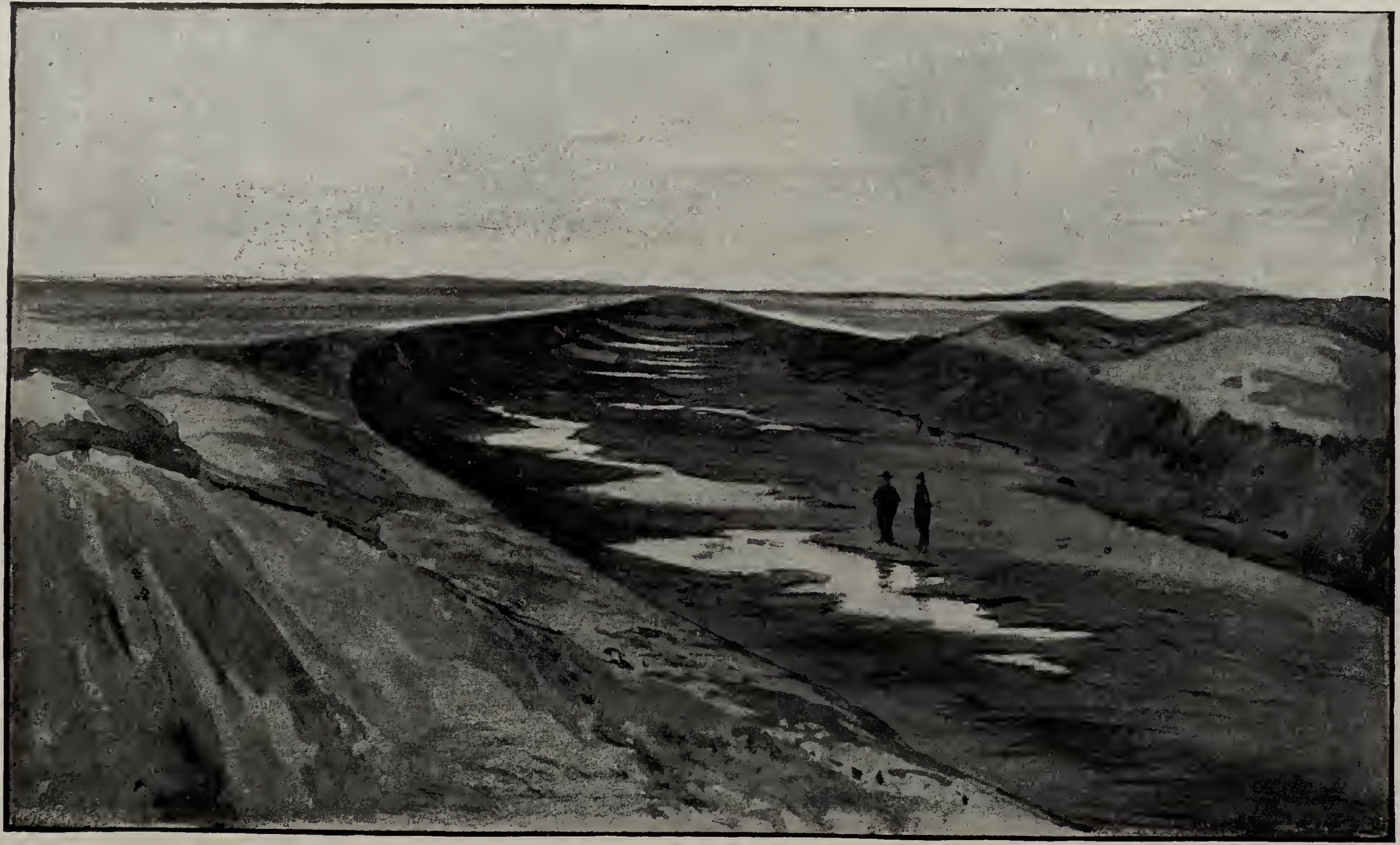


Fig. 83.—Turlock canal tunnel.



TURLOCK CANAL. VIEW OF MAIN LINE.

earth dam below the canal, the total length of which is 180 feet, its maximum height being 40 feet, and its top width 20 feet. The volume of discharge of this gulch is so trifling that it was unnecessary to provide a waste way or escape at this point. Immediately after crossing the gulch the canal enters a cut 8 feet in maximum depth, with the same cross section and grade as the first cut, and having a length of 3,300 feet. (Fig. 66, C.) The canal is now widened to a bed width of 35 feet and depth of 10 feet, and is given a grade of 1 foot per mile. At the end of a mile and a half Peasley creek is crossed on a trestle and flume 60 feet in height and 360 feet long, the water way of which is 20 feet wide and 7 feet in depth. This flume is provided with an escape constructed in its bottom and discharging into two small sloping flumes which lead the water down into the bed of Peasley creek.

At the end of the flume the main canal is reached and traversed for a distance of 11 miles, in which course are two rock cuts, each 3,000 feet long, and respectively 20 and 30 feet in maximum height. In these cuts the cross section is 35 feet wide on bottom, depth of water 7½ feet, and grade 5 feet per mile. The remainder of this length of the canal varies in cross section according to soil, but the majority of it has a bottom width of 70 feet, and depth of water of 7½ feet, slopes 2 to 1, and a grade of 1 foot per mile. (Pl. CXX.) Previous to choosing this location a careful detailed topographic survey was made of the entire Turlock district at a scale of 1,000 feet to the inch and in 5-foot contours, and from this map the location was chosen. This is so designed as to take advantage of several natural channels, consisting of the creeks and gulches mentioned, of an old hydraulic excavation, and of the opportunities afforded for excavating two deep cuts by the hydraulic process. To be sure, one slight disadvantage may be claimed because of the large water surface exposed to evaporation by the creation of the various small reservoirs. This, however, is not a defect, for the water supply will exceed the demands for a number of years to come, and these basins act as settling reservoirs in which the turbid water of the river will be freed of much of the sediment which it carries in suspension. Before the water becomes scarce these basins will be filled by sedimentation, and in the flats thus created a canal channel of proper cross section can be maintained. It is expected that in the course of a few years the river bed above the main diversion weir will be silted up to the level of its crest. There are no objections to this, as it is intended to utilize the basin above the weir as a storage reservoir.

The main canal as outlined above consists for the 18 miles of its length of a purely diversion channel, the object of which is to bring the water to the irrigable lands included within the area of the Turlock district. At the terminus of this diversion line the canal will at once begin to do duty by watering the lands, and below this point the main line will be divided into four main branches, each of which will have a bottom width of 30 feet, depth of water 5 feet, and grade of 2 feet per mile, their aggregate length being 80 miles. In addition to these main branches, minor distributaries will be constructed, leading the water to each section of land, and having a total length of 180 miles. The lower discharge branches are so designed as to have a uniform velocity of 2½ feet per second in order that any matter carried in suspension will be held up until deposited on the agricultural lands instead of in the canals.

It is interesting to note that while the contract prices for excavating the two deep cuts by ordinary processes was 48 cents per cubic yard, they were excavated by the hydraulic process for 31 cents per yard, the material being moved half a mile, while gold to the value of $13,000 was saved in the washing, thus reducing the cost of excavating by 4 cents per yard. In the course of the main canal nine falls are inserted in order to reduce the grade. These vary in height from 4 to 11 feet, while the bed width of the channel is contracted from 70 feet to a clear width of 40 feet through the falls. (Fig. 105.)

The contract prices ranging on this canal are of interest, owing to the variety of materials and works encountered. In section one of the main canal was an expensive cut in the side hill slate rock which cost $5.35 per running foot, and required retaining walls of riprap and puddle. The total cost of this portion of the section was $21,490; the second portion of this section was a thorough cut in cemented gravel, clay, and hardpan, the extreme depth of which was 56 feet, and the total cost $25,388 for 90,000 cubic yards, or about 26 cents per yard. Another portion of this section, consisting chiefly of scraper work and sandy loam, contained 53,000 yards and cost $8,760, or about 17 cents a yard, the three tunnels in this section containing 9,560 yards and the approaches 8,000 cubic yards, the total cost of which was $14,219. In all about 1,282,000 cubic yards have been moved in the main canal, while the great diversion weir contains about 32,000 cubic yards of rubble masonry, and is estimated to cost $325,000.

FOLSOM CANALS.

The works of the Folsom Water Power Company, situated on both banks of the American river, near Folsom, California, are the most substantial and elaborate of their kind that have been constructed either in this country, Europe, or India, so far as the writer's experience indicates. These works are built with the object of furnishing water power to the state prison of Folsom, after which the water used in producing the power passes on to the irrigable lands which the canals will develop in the near future. The chief feature of interest in connection with these works as at present constructed is the massive and substantial character of the diversion weir which is situated on the American river, 1½ miles above the town of Folsom, and of the main diversion canal which is completed as far as Folsom. (Fig. 84.)

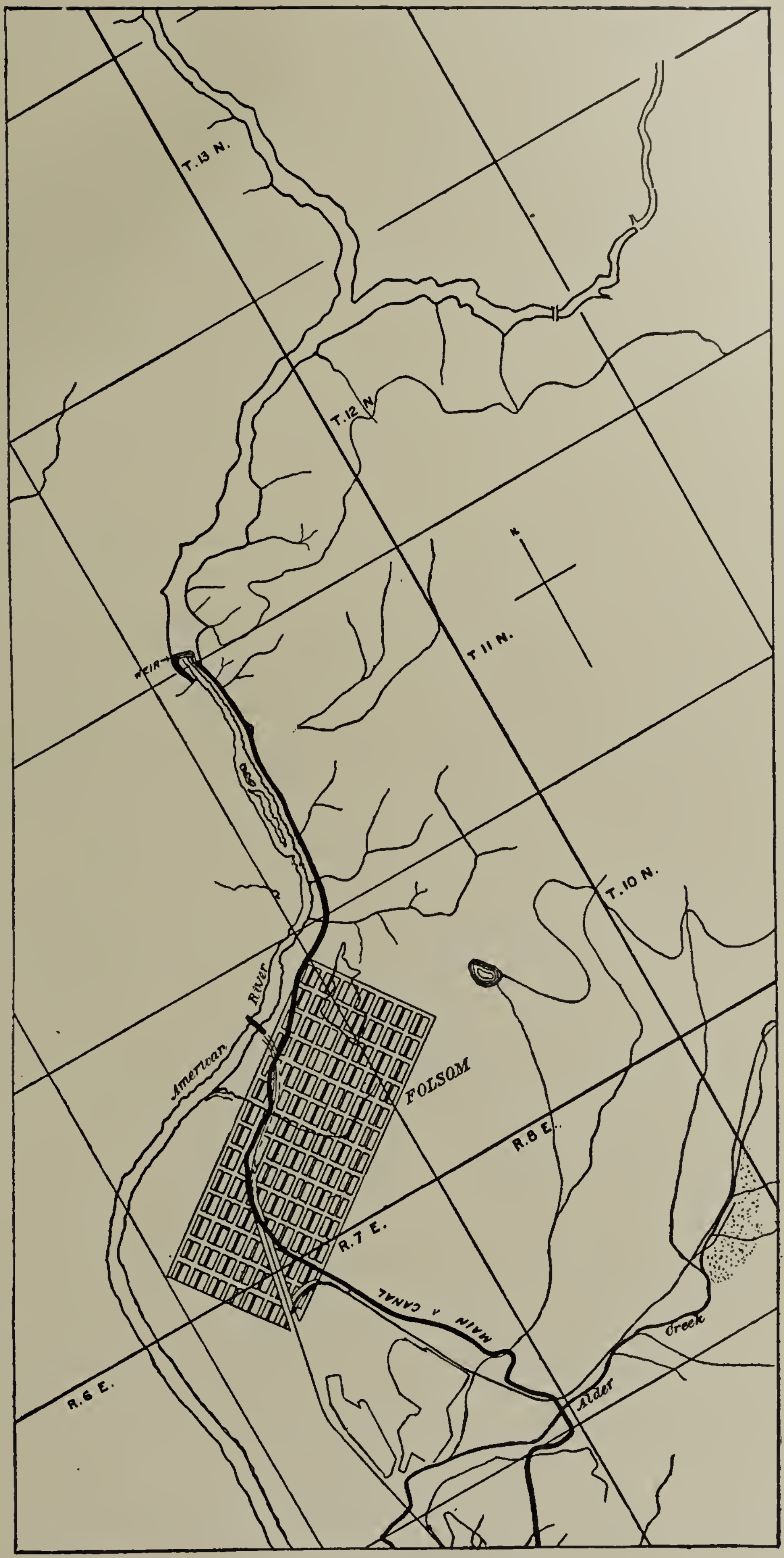


FIG. 84.—Folsom canal system.

The works of this company are not constructed solely for purposes of irrigation. It is intended to use all of the water carried in the main east side canal for water power. It is likewise proposed to mine the dry bed of the river below the main dam and some of the water will be used in hydraulic mining along the line of the ditch. The main bulk of the water will undoubtedly be used however to irrigate the broad expanse of the Sacramento valley which sweeps in along both sides of the American river and will be readily controlled by extensions of the present canals north and southward. Here are hundreds of square miles of the finest kind of fruit land needing only irrigation to make them among the most desirable lands in the state. Some small portions of this area is already under cultivation in the neighborhood of Sacramento, Galt, and other cities, and on them profitable crops of peaches, apricots, plums, grapes, and small fruits, and all varieties of vegetables and grains are now cultivated.

One of the peculiarities of this project is the arrangement by which it was constructed in cooperation with the authorities of the state prison which is situated near the site of the dam. In consideration of the water power company giving the prison authorities about 400 acres of quarry lands adjacent to the prison and right of way through the company's property for a railway, and a 7-foot head of fall in the prison yard for the generation of water power from the entire discharge of the eastern canal, the prison authorities have given to the company all the labor required in the construction of the dam and the first mile of the east side canal, this labor being performed by the convicts.

There has been expended up to the end of January, 1891, on this enterprise $557,382, not including $112,000 appropriated by the state of California for the construction of the power house and first fall in the prison yard. In order to complete the work now in hand, consisting of the main dam and the heavy hillside work in the first mile of the east side canal it is estimated that there will be required an additional outlay of $35,000, and that there will be an available fall at Folsom of 60 feet, which will develop upward of 4,000 horse power. The sources of income will be about 300,000 acres of timber land adjacent to the river; the sale of power to operate the sawmills, etc.; the mines in the bed of the American river; the extensive quarries on the land of the company adjacent to the canal; the sale of water for the privilege of power, and finally the most lucrative source of income will be from the sale of water for the purpose of irrigation after it has been used for creating manufacturing power. With very little expense for additional diversion lines the waters of the canal can be placed on upward of 125,000 acres of land, thus enhancing the value of this land at least $50 per acre.

The American river rises in the high Sierras and has its source of water supply among the numerous lakes and minor streams of those mountains, the area of its catchment basin being 1,900 square miles.

The rainfall on the upper catchment basin of this river varies between 35 and 70 inches per annum, its run-off being equivalent to a depth of from 15 to 18 inches per annum. No gaugings of the discharge of the American river have as yet been made, though unquestionably at the lowest season of the year this discharge is more than sufficient to supply both the east and west bank canals at all times, and if it should at some future time be desirable to increase the dimensions of these canals the amount of water available can be greatly increased by impounding in mountain storage reservoirs great volumes of flood water which only run to waste during a large portion of the year.

The great diversion weir (Pl. CXXVI) was designed and built under the direction of Mr. C. A. Humbert, chief engineer. This work is constructed of the best coursed granite rubble in cement. The main tangent of the weir across the channel of the river is 250 feet in length, while the first 250 feet of the canal on the east bank of the river is built as a prolongation of the weir, thus giving about 500 feet in length of discharge over which the floods can fall. This weir is 24 feet in width at top and 98 feet in maximum height. The center of the weir for 180 feet in length is lowered 6 feet and forms an overfall weir which is closed by an iron shutter the height of the opening.

The west and east side canals head at either end of the weir. Immediately in front of and above the head of the east side canal are a set of four under-sluice gates placed 6 feet below the grade of the canal and discharging back directly into the river. (Pl. CXXXII.) These gates, like the regulating head and all the first portion of the canal line, are constructed, as in the weir, of massive granite masonry, each of these under-sluice gates being 5 by 6 feet in the clear, and opposite and below them is a subgrade in the canal bed across its entire width, in which sediment will be collected and from which it will be sluiced out by opening the gates. The head gates themselves are three in number, each 16 feet in width and 12 feet high, and are of wood heavily trussed with iron, and slide between granite piers and abutments. Below the head gates the first mile and a half of the canal, as far as the town of Folsom, is excavated on a steeply sloping granite hillside. This canal is 8 feet deep, 34 feet wide at the bottom, 50 feet wide at top, and is given a grade of 0·005 in 1, which produces a velocity of 3·6 feet per second and a discharge capacity of 1,210 second-feet. The banks of the canal and the dry rubble outer wall are given a slope of 1 on 1, the slope of the country rock above the maximum water line of the canal being ½ on 1, and the top width of the lower retaining wall 10 feet. In the first 1,700 feet of the canal are seven sand gates, each 5 feet wide by 10 feet high, and similar in construction to the scouring sluices and other works. These are of masonry set in the loose rubble bank on the lower side of the canal and discharge into the river. Their object is to clear the water as far as possible from the sediment before it passes through the turbines.

In time of flood the American river carries in suspension great masses of sediment which it is anticipated will silt the reservoir up in the course of a few years. As originally designed it was intended to flush out the reservoir by means of a set of three under sluices constructed near its bottom. It has been found, however, that the effect of these in clearing the reservoir of silt is extremely local, merely a channel way kept clear behind them. The results of the endeavor to scour out the reservoir in this way have proven similar to those arrived at by the Indian irrigation engineers described by me in a previous report on Irrigation in India.[1] The weir is now intended to be used merely as a diversion weir and is kept clear of silt for a depth equal to the depth of the canal by means of the great shutter along the crest of the weir, which is described in detail elsewhere. As an indication of the magnitude of the floods in the river it may be stated that a depth of 31 feet of water has passed over the crest of the weir on the occasion of one high spring flood. In that year a depth of 30 feet of wet silt was deposited in the reservoir, and at the same rate it would take but four years to completely fill the reservoir with silt. In addition to the other works described in connection with this system there have been constructed one-half a mile above the main weir three masonry piers for log booms; these piers are each 60 feet high and 15 feet square on top, and between them are flood booms attached to railroad iron which is let into the masonry.

The canal is built directly over the river bank in the granite bluffs, as far as Robber ravine, a distance of 1 mile. This ravine is crossed on a high fill, through which is a masonry culvert. Below this point the canal alignment works away from the river a little, passing through the lower portion of Folsom, just beyond which are crossings of Humbug ravine and Willow creek, the latter quite a large stream. Again the canal skirts the river bank for a couple of miles to Alder creek, the largest stream crossed in its line. Beyond here it swings away from the river in such manner as to command all the land lying between the American and Cosumnes river, into which stream it may finally tail.

OTHER IMPORTANT CANALS.

The canals above described are the more important ones now in operation in the west, both from an engineering point of view and because of their magnitude. In addition to these, however, there exist a number of other works, some of which are of nearly equal magnitude, but none of which exemplify so well the present stage of engineering progress in the construction of irrigation works. Of these other canals there are many in Colorado and California, a few of which will be briefly described here.

The canal of the Colorado Land and Water Company derives its supply from the Arkansas river, about a mile above the town of Fosdick. The Arkansas river at this point discharges an abundance of water not only for the demands of this, but for those of several other canals which are diverted from it at different points along its course. The canal is diverted from the north bank of the river, and after skirting the bluffs for about 25 miles passes out on to the level of the sloping bench lands to the north of La Junta. It is 75 miles in length and 35 feet in width at its bottom. Its slopes are 1 on 2, and the depth of water is 8 feet. The grade of the canal averages about 12 feet per mile and its capacity is 900 second-feet. Below this canal are many thousand acres of excellent land, of which about 50,000 acres are directly irrigable from it.

---

[1] Twelfth Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation in India, by H. M. Wilson.

On the bench land below the canal are a number of natural depressions, making cheap reservoir sites in which the flood waters of the Arkansas river can be stored during the periods of the year when the canal is not in use for irrigation. In all there are about ten of these reservoir sites on the line of the canal, ranging from 300 to 20,000 acres in superficial area, and they are capable of storing enough water to double the irrigating capacity of the canal. The head of this canal consists of a simple cut in the Arkansas river, with no diversion weir. In the canal, at about a mile below its head, are regulating and escape gates constructed of wood and operated by screws. The escape consists of twelve gates, the total width being 40 feet and the length of the channel returning the water to the river 800 feet. The sill at the head of the canal cut is 3 feet below the level of the bed of the river. The work on the canal for the first 25 miles of its length is in steep hillside excavation in slate and shale. This work is partly in excavation and partly in fill, though sometimes it is wholly in excavation. In this portion of the canal are some very heavy fills, and the work is of such a character as to render the construction very expensive. The banks in this portion of the work are generally 8 feet wide on top, but in the larger fills they are 10 to 12 feet wide, while the height is increased in order to provide against subsidence and accident. This first 25 miles consists wholly of diversion line, the object of which is to get the water on to the irrigable lands, and for excavation alone it cost $216,000, while the flume and headworks cost $35,000 more. The total cost of the entire canal was $460,000.

This company owns 72,000 acres below the canal, for half of which they get a title from the state at a minimum cost of $2·50 per acre upon the completion of the work and on the remaining half they have a five-years' lease at an annual rental of 2½ cents per acre until 1892, after which the lease is raised to 5 cents per acre and runs for five years longer. In return for this the state required that the company should build the canal of sufficient capacity to irrigate all of its own lands and the state-leased lands, while water rights must be reserved and attached to all of the state lands, though the state is required to purchase these.

There is now being constructed in the neighborhood of Modesto, California, a great canal for the irrigation of the Modesto district. This canal is diverted from the north bank of the Tuolumne river near La Grange and uses as a diversion weir the great dam constructed in common by this district and the Turlock district, which is described in connection with the latter work. The Modesto district was organized in 1887, and bonds to the amount of $800,000 were issued in 1889, of which about $200,000 worth have already been sold. The assessed value of all the property in the district is about $3,360,000, or four times the bonded indebtedness. The preliminary plans and estimates for this work were made in 1887 by Mr. C. E. Grunsky, civil engineer, though the engineer at present in charge of the construction is Mr. O. Winningstad.

The first 2 miles of the canal follow the steep bluffs of the river, which are in places nearly perpendicular, while the formation is slate, with some hard rock. The canal will be supported throughout most of this portion of its length, like that of the Turlock district, by an outside retaining wall of rock, inside of which will be a puddle wall riprapped on the water surface. The grade on this portion of the canal is 1·5 feet per 1,000, the bottom width 16 feet, with depth of water 7 feet and slopes of one-fourth to 1. The capacity of the canal is estimated at 640 second-feet, with a velocity of 4·9 feet per second. In the flumes which cross the larger gulches the grades and velocity will be greater. The bed width of these will be 10 feet, with a depth of 7 feet of water. After the first 2 miles of its length the canal leaves the steep slopes of the river and goes out on to the irrigable bench lands, where the only difficult work will be the construction of a tunnel about 12 feet in length and the crossing of two deep canyons. In this portion of its line the bed width of the canal will be 28 feet, grade 1 foot to the mile, slopes 1 on 2, depth of water 7 feet, and velocity 2·14. The amount of material to be moved in the construction of this canal is 500,000 cubic yards of earth and 200,000 cubic yards of rock, while the construction of 25,000 cubic yards of retaining wall will be required. The length of the main canal is 22½ miles. On it are nine flumes, aggregating 3,400 feet in length, for the construction of which will be required about 800,000 feet of lumber. The highest trestle will be 90 feet. There will be twelve falls on the line of the canal, the highest of which will be 16 feet. This canal is so designed as to irrigate about 80,000 acres of land which are included within the district. The total cost of the main line will be about $250,000, while the distributing system will cost about $300,000 more.

The canal of the Kern Valley Water Company is interesting because of some of the idiosyncrasies in its construction. It has two main lines, one of which was built for the reclamation of swamp lands in the Buena Vista slough and the other as the distributing canal. The principal canal is on the west side of the district following generally the border of the swamp lands for a distance of 24 miles. It derives its water supply from the lower end or outlet of Buena Vista lake; it is 125 feet wide at the bottom and is designed to carry 10 feet in depth of water. It was originally constructed on a grade of 1½ feet per mile, with cheaply constructed wooden falls to neutralize the slope of the country. These, however, were soon carried away by flood and it has eroded its bed until its grade is now 4 feet per mile. Owing to the fact that its lines are nearly straight this high grade and consequent high velocity have done comparatively little damage other than to add to the expense of diverting water from the canal. Its side slopes vary from 1 on 3 to 1 on 7. As a result of its erosion the present grades are extremely irregular. For half a mile the grade is 0·9 of a foot per mile, for 9 miles it is 2 feet per mile, for 3 miles it is 4 feet per mile, for one-half mile it is 2½ feet per mile, for 1¼ miles it is level, after which is a vertical drop to a grade of 1·6 feet per mile then for 1 mile its grade is 8 feet per mile. Below this main canal a parallel distributing canal 30 feet wide on the bottom and 2 feet deep was constructed with a length of 10 miles. On the east side of the swamp is a canal 6 miles long built for irrigating purposes and having a bed width of 25 feet and depth of 3 to 5 feet and side slopes of 1 on 3.

The capacity of the main western canal is 6,000 second-feet. It acts both as a drainage and irrigating canal. When the Kern river is in flood it carries the water off and spills it on to the waste lands in the lower San Joaquin valley. When the river is low it diverts this and the water of the Buena Vista lake for irrigating purposes. Owing to the retrogression of grades the bed of the canal is generally 16 feet below the surface level of the country.

CHAPTER V.

HEADWORKS.

The headworks of a canal are usually located at a point where the stream emerges from the hills. At such a point the slope of the country as well as that of the stream is generally steep, and as a consequence, by locating the headworks there, the canal can be conducted to the irrigable lands in such manner as to command them with the shortest length of diversion line. Another advantage in locating the headworks high up on the stream is that the canal is thus enabled to command the largest amount of irrigable land. Still another advantage is, that the width of the channel of the stream is generally contracted and it usually flows through some hard material, possibly rock, the result being that the length of the weir is thereby reduced, as well as the character and cost of the structure to be built.

The weirs constructed in this country are of various designs and material. Until recently little attention has been paid to their location or permanence. Too much careful attention can not be given to the examination of the stream at the point of diversion. Soundings should be made, the velocity of the stream and its flood heights studied, as well as the character of the banks and bed of the river. In comparison with similar works built in other countries the headworks of most American canals are of extremely temporary and transient character, and are almost entirely constructed of wood. It is unfortunate that more permanent headworks have not been constructed, depending for their value, as the rest of the work does, upon stability. It is impossible to form wood, with the smallest allowance of iron and little or no masonry, into substantial and permanent headworks, and the majority of American engineers are not proud of their work in this direction.

In the earlier canals constructed in Colorado and California the headworks were of the most simple character, consisting generally of a cheap crib dam weighted with gravel or rock, sometimes only a brush dam, and at others a simple barrier of two rows of sheet piling filled in with sand. At one extremity of this a simple cutting for the canal head is made and a wooden flume let into it in which are constructed wooden gates. This is the most usual form of headwork, and perhaps nine-tenths of those in this country consist of modifications of this general plan. It is to be hoped that when the present works are destroyed they will be replaced by others of a more substantial and permanent character.

An example of the error and expense of this class of work is afforded by the Arizona canal. Owing to the pressure brought to bear on the engineer of this work to construct it in the shortest possible space of time a rough crib dam was at first thrown across the river at a cost of several thousand dollars. The life of this was very short, as it was destroyed the first year after its completion. Again the company ordered its immediate repair and reconstruction, and the engineer built a more substantial work in the short period of a month or so at a cost of about $25,000. This work had not been in place over three years before the great flood which occurred in the spring of 1891 destroyed it. At last the company have awakened to the necessity of choosing a proper location for this headwork, as well as constructing one of a sufficiently substantial character to enable it to cope with the great floods which it has to withstand. The headworks of several canals in southern Colorado, as well as those on the Kern river in California and at other points, have been constructed by simply driving piles into the soft bed of the stream on which a floor rests, and of inserting planks or flash boards between these to the desired height of the diversion.

A more substantial character of headwork is being constructed on a few of the later canals. At the head of the Turlock and Modesto canals a substantial masonry weir is being constructed which will doubtless last for ages. Likewise at the head of the Folsom canal, in California, the weir is of the most substantial granite masonry and the regulators and other works connected therewith are of like material; the gates which close these being of iron. Substantial loose rock and earth dams hawe been built at the heads of the Pecos and Idaho canals, though in the case of the former the regulating gates are of wood, very substantially constructed, while those of the latter are of iron work in masonry piers.

WEIRS.

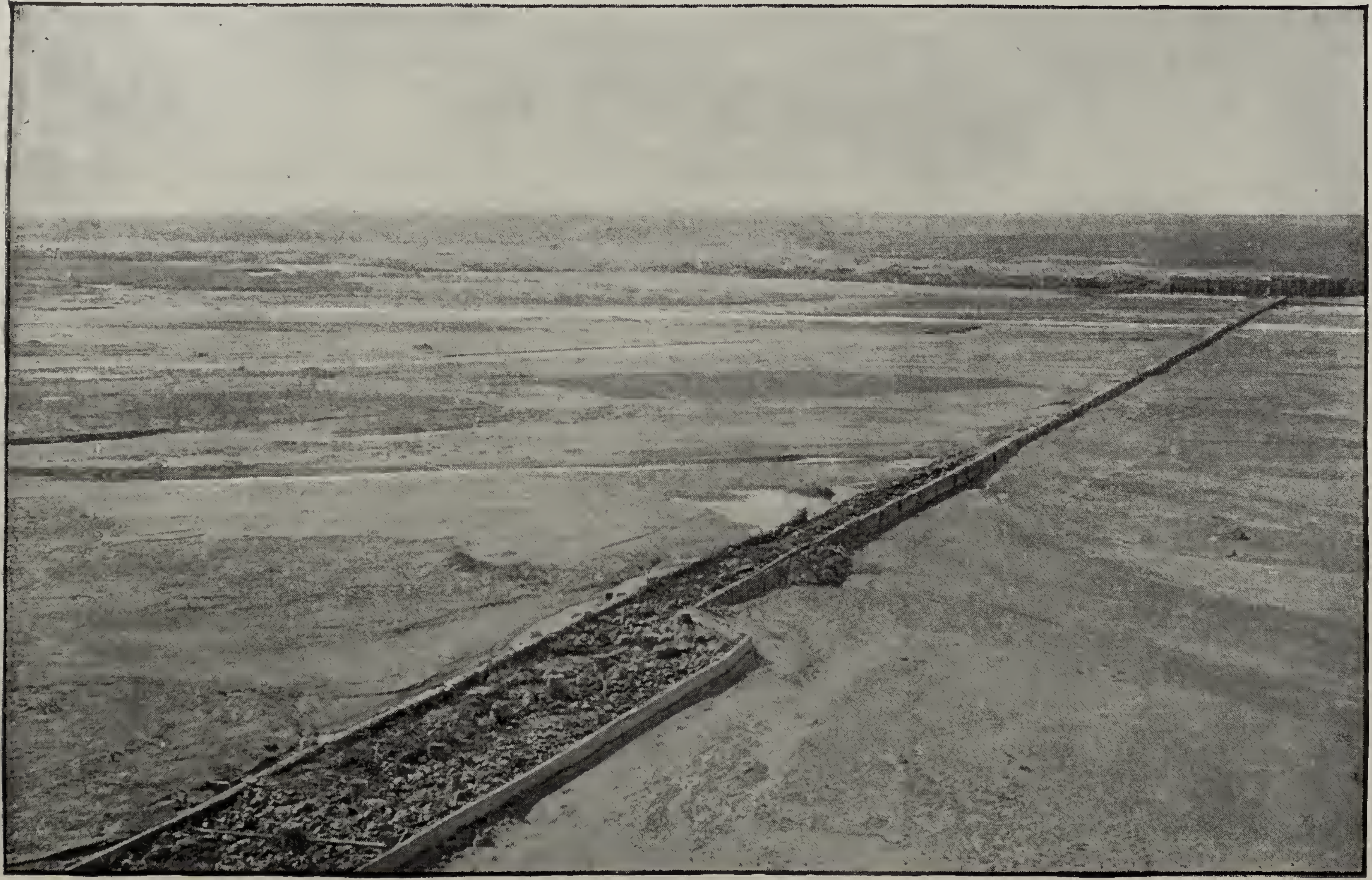
The weirs which are built by American engineers for the diversion of water into irrigating canals should be classed according to the mode of construction of their superstructures, rather than according to the mode of building their foundations, as is necessary in describing the weirs built on Indian rivers. There is great similarity in the foundations used on American works, only differing, as they do, according to the material in which they are built. In sandy rivers or those having deep beds of alluvial deposit, pile foundations or crib dams are most generally employed. In hardpan or rock the foundations differ little in character from the superstructure itself, which is merely a continuation of the former.

The simplest and crudest form of weir is the plain brush and gravel dam, which was formerly employed by the Mexicans and is still used to a limited extent on minor streams. Loose rock thrown in across the beds of smaller streams belongs to the same order. Double rows of piling sheathed over and filled in with gravel or sand, as on one or two Colorado rivers, is simply an amplification of the above general design. Successive improvements to these are crib weirs; wooden frame flashboard weirs founded on piles, as those at the head of the Calloway and Del Norte canals; dams built of loose rock, or loose rock and earth, as those at the head of the Boise and Pecos canals; and, finally, solid masonry weirs, similar to those at the head of the San Diego flume, the Turlock and Folsom canals.

It is almost impossible to trace out the earlier history of ancient weirs constructed in this country for the diversion of water for irrigation purposes. As with all other works connected with our irrigation projects, many methods of design and construction have been copied from the works of other and older countries, as well as from the works constructed in the eastern portion of the United States. Nevertheless the earlier stage of all irrigation development in the west is marked by a striking absence of any knowledge of work done either in the eastern states or elsewhere, and the crude beginnings were usually worked out independently for each case. It was not until the later and more advanced works were begun that ideas were borrowed from other sources.

How the Pueblos or earlier inhabitants of the southwest managed the diversion of the water for their canals is not known. The earliest works for purposes of diversion, of which we have any knowledge, were those constructed by the Mexicans a century or more ago. These were generally of the crudest and simplest form, consisting of a brush or bowlder dam thrown across the river with a view to diverting a small portion of the discharge of the stream. They were annually carried away and destroyed by the floods and rebuilt. At the head of the Zanja Madre, the main irrigating ditch for the city of Los Angeles, the only form of diversion yet employed is that inaugurated by the earliest Mexican settlers and consists of a simple ridge of sand and gravel thrown up and piled upon a little brush. The total height of this weir rarely exceeds a foot or two.

The first works built by the American irrigators were, like the rest of their canal works, copies of and occasionally improvements on the earlier Mexican structures. An example of these is afforded by the brush and bowlder dams constructed near Phœnix, Arizona, at the head of the Grand and the Salt river canals. These weirs were formed of stakes, brush, and bowlders rendered water-tight by filling in upstream with gravel and sand. The method of laying them consists in a man going into the stream and driving stakes across the channel. Between these fascines or bundles of willows about 3 inches in diameter at the butts are laid with butts downstream, their upper branches being weighted with bowlders. Willows, cottonwood, and tule reeds are again laid on,



VIEW OF PILE WEIR ACROSS PLATTE RIVER, COLORADO.

and on the top of these bowlders are laid alternately until the dam is built up to the required height, which rarely exceeds 5 feet. If not destroyed too soon, the willows sprout, thus forming a living mass of vegetation and gravel.

A later weir, an improvement on the brush and bowlder weir, is represented by the pile weirs which are built across some of the sandy rivers of Colorado. One of these (Pl. CXXI) is thrown across the Platte river in Colorado. It consists of a double row of piling driven into the river bed, the two rows being about 6 feet apart and the piles in each row 3 feet apart between centers. Between these is driven sheet piling, and the upper portion of this structure is planked over so as to form a rectangular wall, between which is filled in with gravel, sand, etc. Walls or weirs of this character are not given any great height above the bed of the river on the lower side, rarely exceeding 10 feet. After they have been filled in behind with the accumulations of silt brought down with the stream, they form substantial and firm barriers, some of which have been in existence for ten or fifteen years.

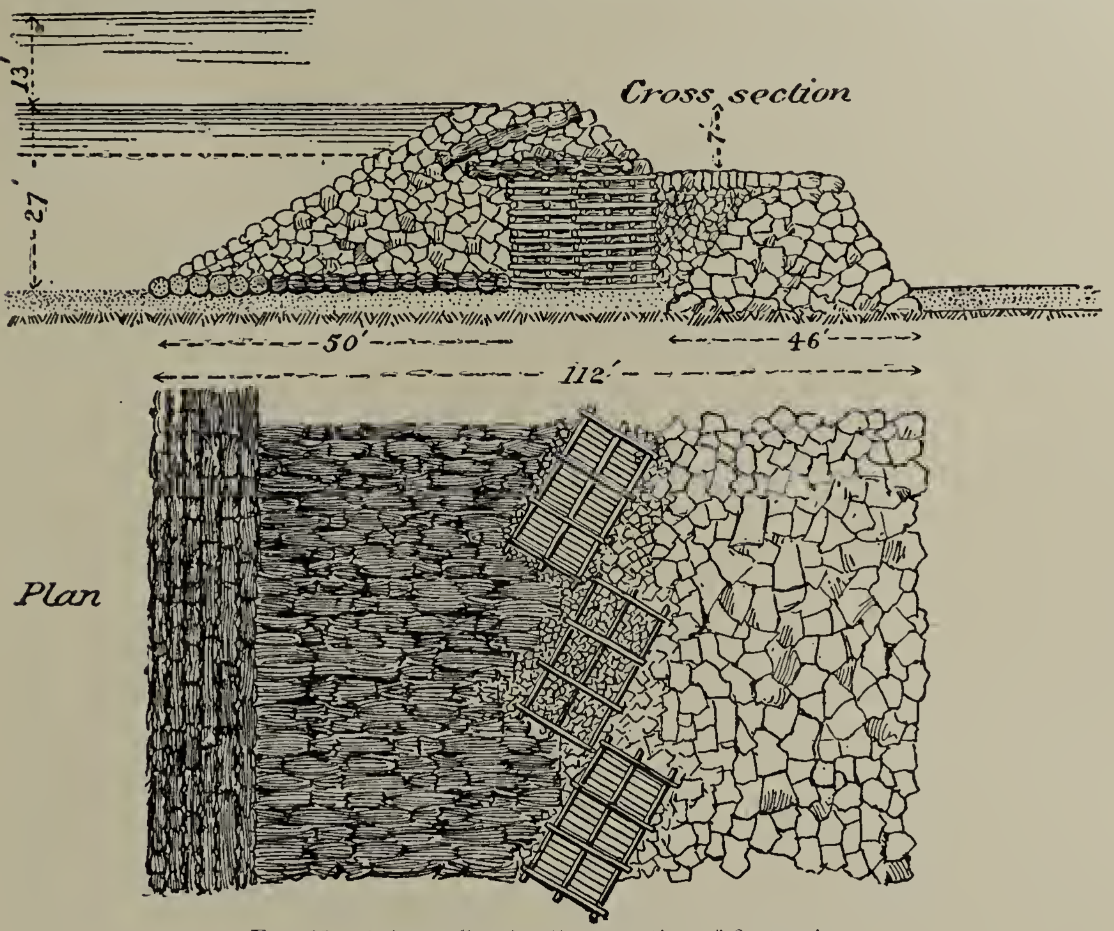


FIG. 85.—Arizona Canal. Cross section of first weir.

CRIB WEIRS.

An excellent example of the rock and crib weir is furnished by the work at the head of the Arizona canal near Phœnix. The weir at the head of this canal has been constructed and destroyed by floods three times, the third weir being now under construction at this point. As before mentioned, the bad location and cheap form of construction of the earlier of these weirs was the result of haste and pressure on the part of the owners. The first weir built at this point is illustrated in Fig. 85. It was constructed of rubble and crib work 173 feet in length and 16 feet in height at the deepest point. The mode of construction of this weir consisted in throwing in stone of from 1 to 3 tons in weight from a pontoon moored upstream. These were thrown across the river until a bar was formed which caused the water to spill over it the entire width of the channel. The water then flowed between these blocks until it filled their openings with shingle brought down from the river bed above. Cribs were then formed 12 by 22 feet, consisting of three 24-foot logs, each 12 inches in diameter and 6 feet apart, on which were secured cross wise, four 14-foot by 12 inch logs about 7 feet apart, spiked together by iron bolts. Between these 2-inch planking was spiked to the longitudinal logs forming a platform. These cribs were built to a height equal to the depth of water where they were to be sunk and were floated out and placed in position. They were then loaded with stone until they sunk to the desired depth, and were filled up to the water surface. As shown in the illustration they were placed diagonally to the line of the main weir so that they overlapped. Fascines were made of willow 2 feet in diameter and filled with stone. These were put in position in the direction of the current, one end touching the crib work along the whole bed. Another series of fascines of five rows were laid across the stream against the upper end of the first series and on these bowlders and gravel were deposited, and also on the rock breakwater up to the level of the crib top, 16 feet above the river bed. Twenty-four fascines were laid over the crib top parallel to the stream, overlapping the bowlder work and filling and binding the whole together. The bowlder and gravel filling was then continued 8½ feet higher, at which level a finishing layer of fascines 10 feet long was laid. This weir with the adjoining head works cost $10,000.

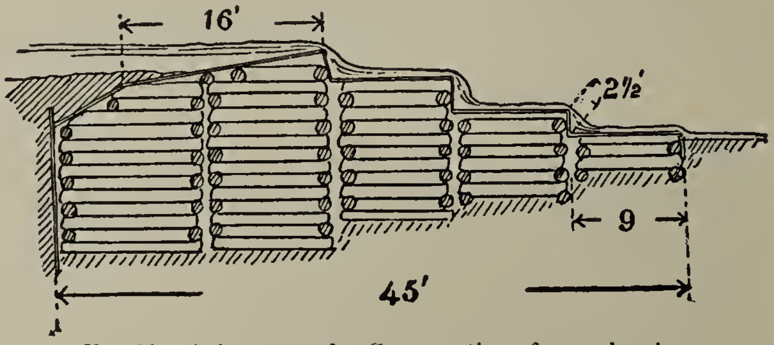
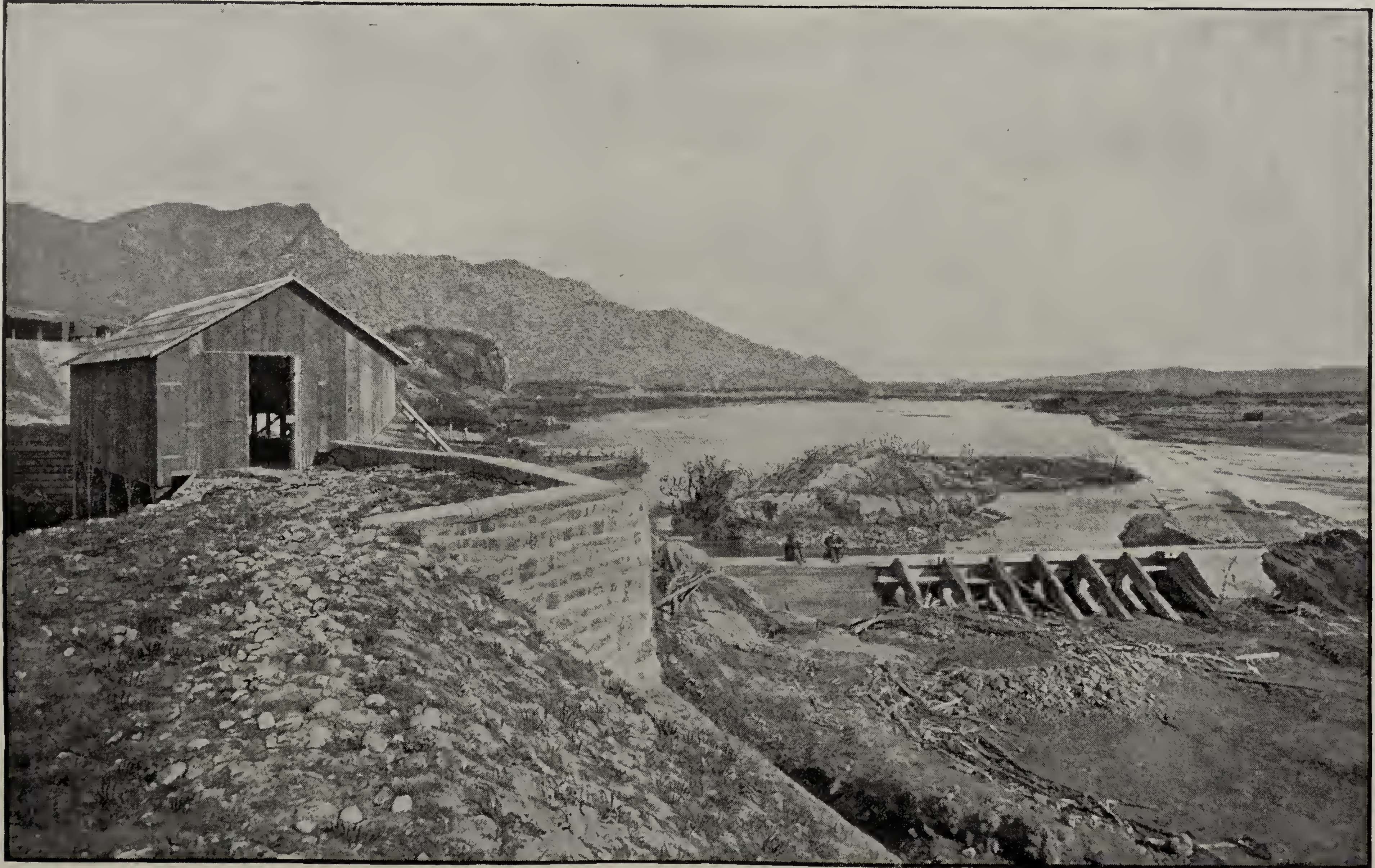


FIG. 86.—Arizona canal. Cross section of second weir.

The second weir built by this company to replace the one above described, which was destroyed by flood, is shown in Pl. CXXII, and its cross-section in the sketch, Fig. 86. It was constructed of crib boxes of rough hewn logs, about 9 feet long each, driftbolted and wired together and filled with rocks. The weir extends diagonally across the river in a northerly direction from a rock on the left bank. At the



ARIZONA CANAL. VIEW OF SECOND WEIR.

time of its construction the river channel was against the right bank, and on the left was a gravel bar sloping toward the right bank to a depth of 8 or 10 feet. This was excavated to low water surface for a width of 60 feet, and the construction of the dam was commenced with its base at low-water surface upon mudsills 8 by 10 by 48 feet laid with the stream at intervals of 10 feet. Upon half of these is built a continuous crib work with cross-ties every 10 feet. Alternate rails and cross-ties were gained into these, leaving a space of 4 inches between the rails and fastened with three driftbolts. The front and back sides have a batter of two-thirds to one, and are covered with 2-inch planking above and at the back of which 6-foot sheet piling is driven in. The crib is filled with bowlders in such a manner that the height of the crest of the weir above low water for a distance of 416 feet from the north end is 11 feet. On the face of the downstream side the rails and cross-ties are wrought together with double rods of seven-eighths inch iron in addition to the driftbolts. Rails are laid on the mudsills projecting 24 feet down stream 4 feet apart, and 6-foot piling was driven on a slant and covered with 3-inch plank. Below the lower end of the apron the gravel was excavated and swinging cribs put in 4 feet deep, 12 feet wide, and of various lengths, from 10 to 24 feet, fastened with double rods around the corners and also by seven-eighths inch round iron. These swinging cribs were filled in with rock and covered with 3-inch plank and fastened to the rail and middle apron with five-eighths inch galvanized cable. The remainder of the weir, that portion which is constructed across the channel, has a base of from 36 to 48 feet, according to the depth of water, and at intervals of 10 feet two mudsills 8 by 12 by 48 feet were wired together with 1-inch cable to act as a hinge between the sections. Each section was floored and cribbed up to a height equal to the depth of the water beneath. The alternate sections were not cribbed, but left open to guard against a rise in the river. These openings were floored with timber on the bottom and sides and fastened to receive drop-timbers to be used in closing afterwards. The work was carried along somewhat like building a pontoon and was then loaded and sunk. Instead of bringing up the face batter like the first 646 feet, two projections were made 8 feet wide and 3 feet high, each to take the place of an apron, below which were attached swinging cribs similar to those heretofore mentioned and wired to the projecting part of the dam at the surface of the water. Where the weir connected with the rock at either end the timbers were bolted to it with 1¼-inch anchor bolts. The weir for 416 feet from the north end is 11 feet in height above low water and the balance of the weir, the total length of which is 916 feet, is 10 feet above low water. As a consequence the first flood waters flow over this portion of the weir. Between the south end of the weir and the canal head gates the rock is blasted out and a wasteway constructed 36 feet in length to receive flashboards. This acts as a scouring sluice to keep the head gates of the canal free of silt. The total waterway over the dam, including this scouring sluice and the rock on a level with the same is 1,000 feet.

As before stated the total length of the weir and apron parallel to the stream in the center of the channel is 48 feet, and the deepest part of the crib work in the channel of the river is 33 feet in height. As shown in the sketch the crest of each successive row of cribbing at the north end of the weir is from 2 to 2½ feet lower than that above, causing the structure to fall away in broad steps, each of which is about 9 feet in length horizontally, thus breaking the force of the flowing water and diminishing its tendency to destroy the work, the last crib being a swinging apron wired to the structure above. Beyond the east end of the weir, that farthest from the head of the canal, is an old channel of the river separated from the present channel by a narrow ridge of rock and gravel a few yards in width. This old channel is blocked by an embankment of gravel 10 feet in height rising to an elevation a little above that of the crest of the main weir.

The location of the head works of this canal was not the best, but their choice was forced upon the engineer, Mr. Sam. Davidson, owing to the limited time and funds at his disposal. By the selection of this site he was able to build the works in much less time and at less expense than by the choice of a better one. A large portion of this weir was destroyed by the great flood which occurred in March, 1891, and a new work is being constructed at the upper site, the location of both the old and the proposed new weir being shown in Pl. CXIII, B. The floods in the Salt river are of great force and duration, and it was in consequence of this that so substantial a character was given this work. In ordinary stages of the river the water flows over the weir to a depth of about 2 inches, with a discharge of about 1,000 second-feet, but this work withstood high floods for four years, the greatest of which amounted to about 140,000 second-feet, with a fall of 12 feet per mile and a depth of 13 feet over the crest of the weir. The flood which destroyed it in the early part of 1891 had a volume estimated at 350,000 second-feet and the velocity of the current as shown by driftwood was about 15 feet per second.

There are no engineering features of especial interest in the weir at the head of the Highline canal on the North fork of the Platte river in Colorado, but it furnishes another example of the crib dam as constructed in the West. The present structure, damming the river at the head of the Highline canal, was rebuilt in 1884 under the direction of Mr. G. G. Anderson, the original weir, which was built under the direction of Mr. E. S. Nettleton in 1880, having been washed out in that year. The original weir was 140 feet long across stream and 30 feet in width at the bed parallel to the course of the stream. The downstream slope of this dam was vertical, while the upstream slope had an inclination of 2 on 1, the two slopes meeting in a short angle. Below the downstream vertical face was an apron of 2-inch planking 30 feet in width. The weir was built in six sections, between each of which was an opening 7 feet wide, extending the whole width and height of the structure. In each of these openings was placed a gate, one of iron swung in halves in the butterfly shape, the other of wooden flashboards. These six straight sluice-ways were put in with a view to increasing the flood discharge capacity of the weir. There was really no necessity for their introduction, as the damming up above the structure by silt deposited from the river did no damage, as the work was not for storage purposes but merely for diversion. These openings weakened the weir and in all probability caused its destruction by the flood of 1884.

The present structure was built to replace that just described, and consists of wooden crib work filled with rock, the upstream slope of which is very flat, while the downstream face is nearly vertical. As shown in the accompanying illustration (Fig. 87) there is a substantial masonry sluice way built near the left bank open the entire depth and width of the weir, by means of which the water in the river above may be drawn down to any desired level. There appears to be little necessity of this sluice way, though it does not constitute the menace to the integrity of the work which its predecessors did, as it and the weir abut against the heavy masonry wall constructed at its end. This sluice way consists of four openings closed by iron gates, each 4 feet wide between centers and 7 feet in height. These gates are raised and lowered by means of screws from above, and the sills of these openings

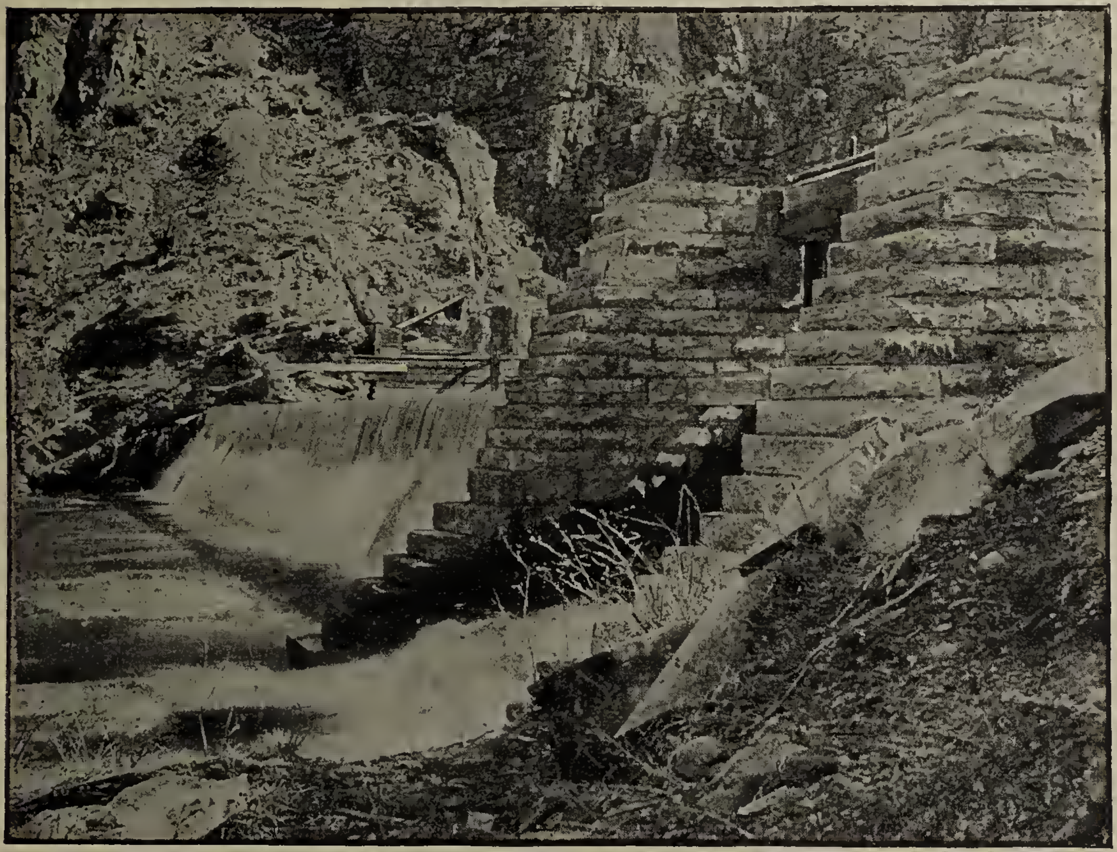


FIG. 87.—Highline canal. View of weir.

are at a depth of 2 feet below the level of the head gates of the canal in order to permit of sluicing out sand, etc., which may accumulate there. The weir itself is constructed of heavy timber crib work filled with broken stone, the upper slope being sheathed with 2-inch planking.

One of the best and most recent examples of crib weir construction is that at the head of the Bear river canal, near Collinston, in Utah (Pl. CXXIII. At the point where this is built the Bear river flows between narrow rock walls, the sides and bed of the stream resting on firm rock, the maximum flood discharges of the river, which are apt to flow over the weir, amounting to about 9,000 second-feet. This weir is 370 feet in length on its crest, 17½ feet in maximum height from the bed of the river to its top, and its greatest width at its base parallel to the course of the stream is 38 feet. The upstream slope is 1 on 2 and the down stream slope 2 on 1, the water falling onto a wooden apron anchored by bolts to the bed rock of the river. It is constructed (Pl. CXXX) of heavy 10 by 12 timber drift bolted to the bed rock and firmly spiked together.

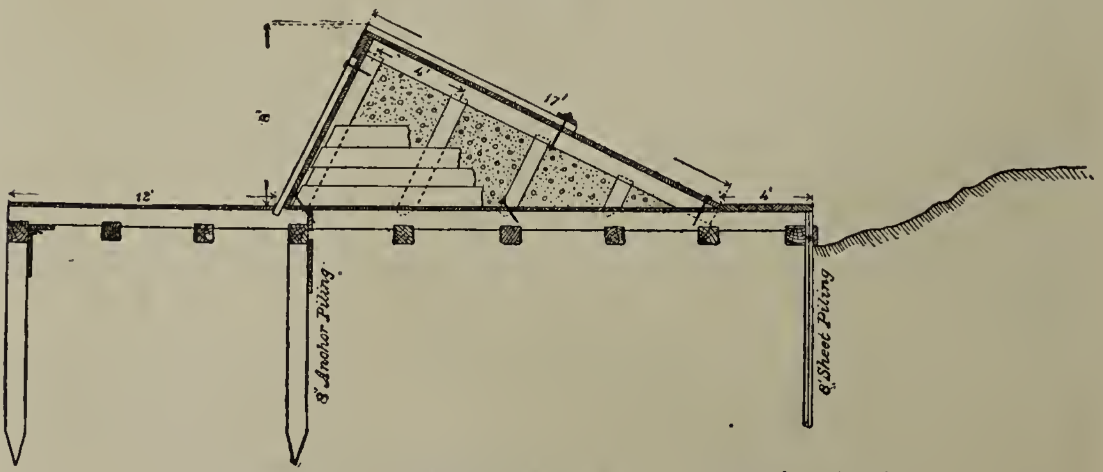
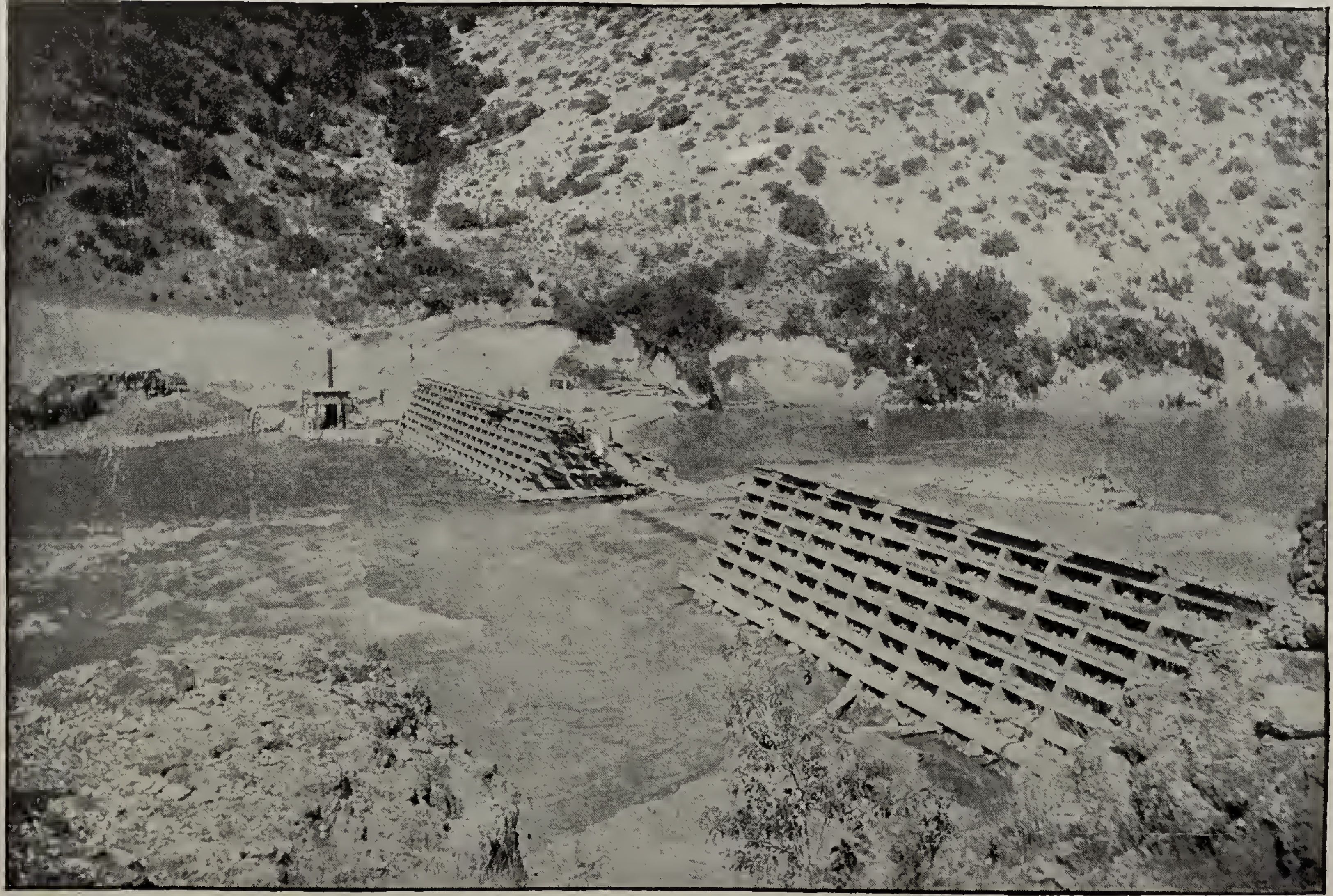


FIG. 88.—Kraft Irrigation District canal. Cross section of weir.

The interstices between these are filled with broken stone and it is backed by earth, the result of the deposit of silt from the river water. At either end of this weir the east and west side canals head, the former in a rock channel excavated from the rock walls of the canyon, and the latter in a solid masonry head, built of rubble masonry in cement, the depth of the foundation of which is 9 feet, while the superstructure is of cut-stone masonry.

Still another and different example of the timber-crib weir is that furnished by the weir across Stony creek, at the head of the Kraft district canal, which is illustrated in Fig. 88. The object of this weir is to raise the water to a height of 8 feet and divert it into the head of the canal. It is 500 feet in length and abuts against the gravel banks and is built on the gravel bed of the stream. At either end it rests against wooden wings built by driving piles into the bank of the river and sheathing them. The total height of these wings or abutments is 10 feet above the crest of the weir, sufficient to prevent the greatest possible flood from passing over or around them. The weir is of tim-



BEAR RIVER CANAL. VIEW OF WEIR DURING CONSTRUCTION.

ber crib work founded on piles and filled with gravel, both faces being framed with 6 by 8 timbers sheathed with 3-inch planking on the upstream face and 7 inches of planking on the lower face. The foundation consists of two rows of piles driven across the entire width of the channel of the stream 6 feet apart between centers, the two rows being 12 feet apart, one resting immediately under the foot of the timbers on the downstream face of the weir, the other resting under the toe of an apron which extends 12 feet below the weir. Eight feet below the lower row of piles is a row of sheet piling, and 22 feet above the upper row or just above the upper slope of the weir is another row of sheet piling, both of these rows being of 4-inch double piling, 8 feet in length and driven to bed rock.

OPEN WEIRS.

The next type of weir which is of sufficient interest to be worthy of note is the open or flash-board weir, such as is that at the head of the Del Norte canal in Colorado and those built at the head of the Merced and Calloway canals in California. This general type of weir consists wholly or in part of a foundation of piling driven into the river bed, upon which is built up an open frame work closed by horizontal planks let into slots in the frame. These planks can be removed or inserted at will, thus increasing or diminishing the effective height of the weir according to the stage of water in the river. They are essentially temporary in character, their chief recommendation being the cheapness with which they can be constructed in rivers, the beds of which consist of a deep layer of silt or mud.

Of weirs of this kind one of the first built is that at the head of the Calloway canal across the Kern river, near Bakersfield (Pl. CXXIV), as a type for all similar structures of this kind. The maximum flood discharge of the Kern river at the point at which the weir is built is about 30,000 second-feet. As shown in sketch plan (Fig. 67, B) the width of the river at the point at which the weir is constructed is about 500 feet. Near its center is built a weir founded on piles and loaded with sand, which is 16 feet in width. In the point of land separating the canal from the river is left a short levee of sand, the sides of which are protected by wooden wings and sheet piling, as are the banks at both extremities of the canal regulator and of the weir. The weir consists of 100 bays, separated by a simple open triangular framework, the width of each being 4 feet. The canal heads in the right bank of the river, and the regulator, which is similar in construction to the weir, consists of 25 bays, each 4 feet wide. Near the left bank the weir rests on an island, between which and the shore are nine additional bays, while the Farmer's canal, a comparatively small work, heads at the end of this. The weir is 10 feet in height above the wooden floor, which is flush with the river bed. The mode of constructing this work consisted in inclosing the area to be built on with sheet piling 10 to 12 feet in length. This area was covered over with a floor placed 2½ feet below the bed of the stream. Above this floor is a second floor 2 or more feet in height, the walls forming compartments which were filled with sand and form a firm box on which the flood waters fall. In addition the bed of the river immediately above and below the transverse sheet piling is protected by similar sand boxes, having a width of 10 feet parallel to the stream and 2 by 2 feet in cross section. There is also an additional row of sheet piling 8 feet above the upstream row. The weir was built in two sections and by different methods, 200 feet of it being built on the old plan, without any sand boxes at the bays, the flooring consisting simply of boards resting on the river bed about 1½ feet below grade line. In building this portion of the weir two lines

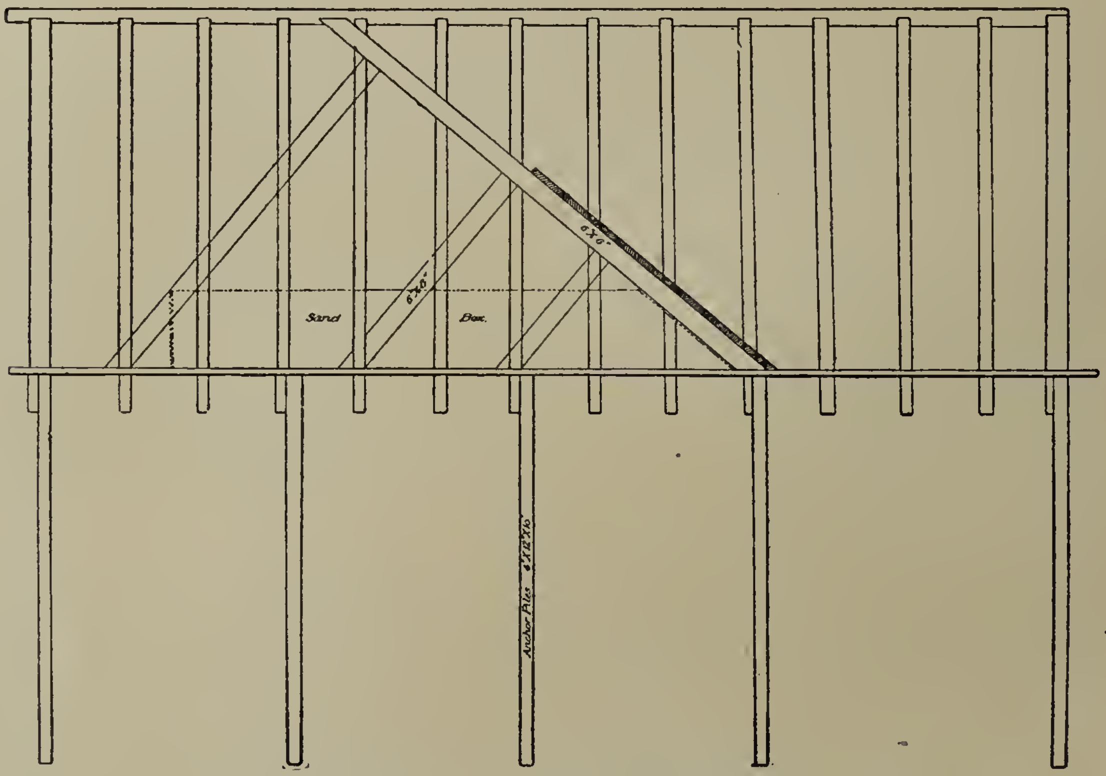
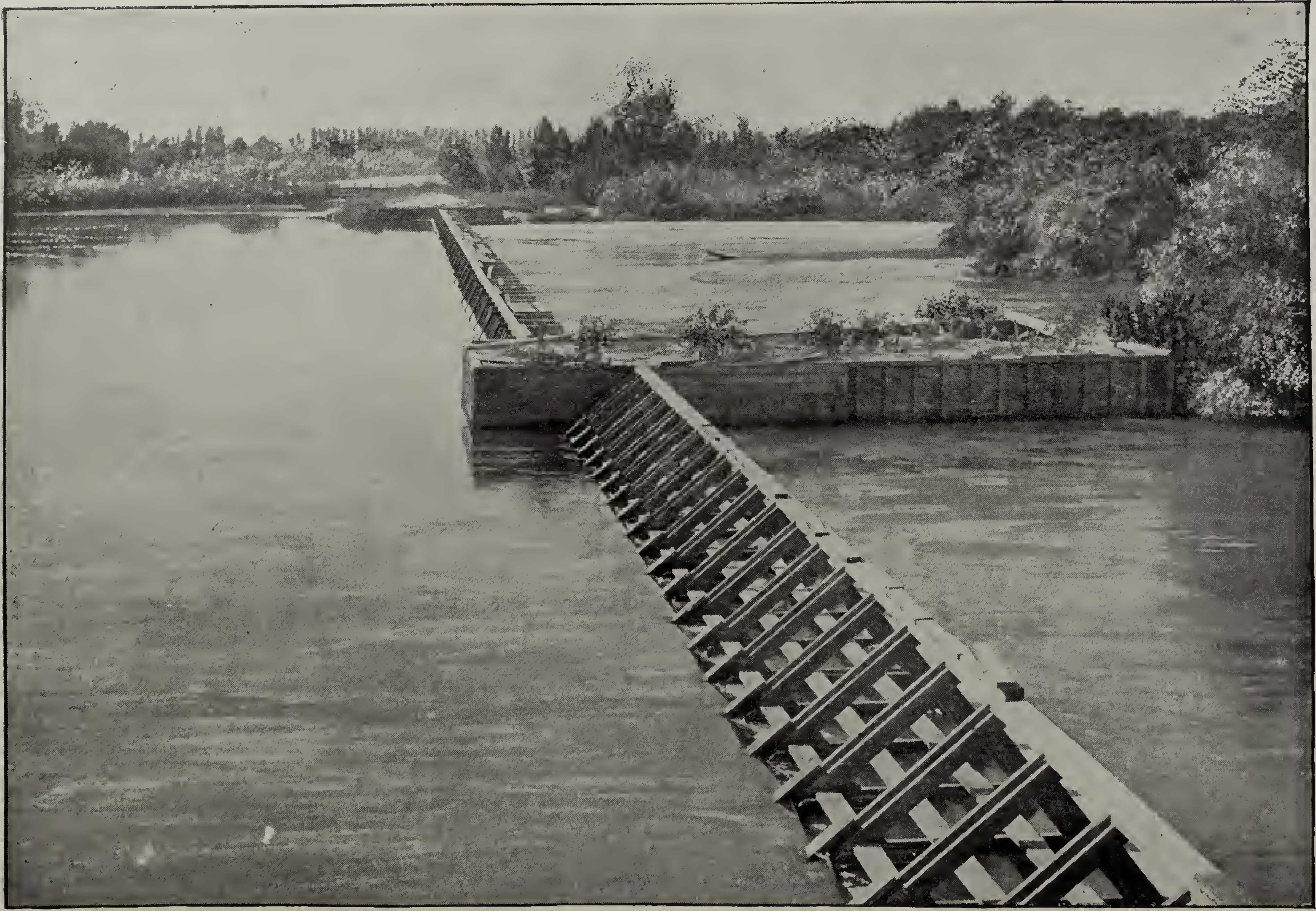


FIG. 89.—Calloway canal. Cross section of weir.

of 12-foot sheet piling 8 by 2 inches were driven 18 feet apart, so that their tops were 12 inches below the river bed. The abutments and the central pier have similar sheet piling that complete and inclose a quadrangle 200 by 18 feet. Between the transverse rows of sheet piling are five 6 by 6 inch joists and one outside of each row, forming waling pieces, to which the tops of the piles are spiked. On these joists a floor of 8 by 2 inch plank is nailed, its width being 20 feet. The intermediate joists are separated by anchor piles at each 9 feet, but their main support is the sand of the river on which it rests. The abutment has flaring wings at an angle of 40 degrees and 15 feet in length. The walls are carried up 8 feet above the tops of the piles and are of 8 by 1 inch planks, retained by 6 by 6 inch walings that are tied to anchor piles in the bank. This construction forms the foundation and ends of



CALLOWAY CANAL. VIEW OF WEIR AND CANAL REGULATOR HEAD.

the weir. The weir proper is movable and is formed of frames or trusses of 6 by 2 inch timber placed 4 feet apart. (Fig. 89). These consist of two pieces, the upstream one being 7 feet 3 inches long, set at an angle of 38 degrees. The other supports it at right angles and is 5 feet 4 inches long. The lower end of these rafters thrust against two pieces of 6 by 2 inch timber, running the whole length of the weir and nailed to the floor, forming mudsills. Two pieces 12 by 6 by 2 inches, into which notches are cut 2 inches broad, are nailed to the floor on the inside of the truss rafters. These trusses are kept in vertical position by means of a footboard 8 by 2 inches. On the upstream part of the truss loose planks or flashboards 6 by 1 inches are laid to the height required and slide between grooves formed by nailing face boards on the trusses. The more recent portion of this dam, the remaining 225 feet and the head regulator is founded, as previously described, with sand boxes to give additional strength to the flooring. Each truss rests on four anchor piles 4 by 12 inches by 10 feet, while an additional anchor pile is placed at either end of the apron. The supports to the main vertical rafter on which the flashboards rest are four in number and of 6 by 6 timber, while the main rafter is of 6 by 8 timber.

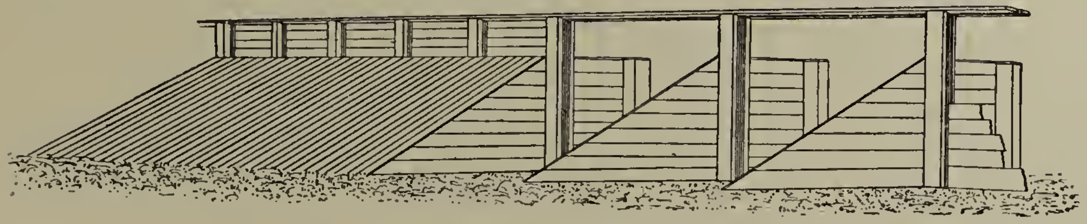


FIG. 90.—Monte Vista canal weir.

A modification of the open weir just described is to be found in the combined solid weir with sluice openings through it, such as that built by Mr. Walter Graves at the head of the Monte Vista and Del Norte canals, in Colorado. These structures differ chiefly in that they are made of rough hewn timbers, rudely but firmly put together, and in that a portion of their length is closed simply by nailing planking on to the sloping rafters and allowing sediment to silt up and weight this down. The weir at the head of the Del Norte canal (Fig. 68), consists of an earth bank extending for a short distance into the stream. The end of this is protected by wooden planking for abutments, and from it the weir extends to the left bank of the river, opposite the canal head. In the center of this weir are seven openings, each 6 feet wide. The work is founded on piles sunk 10 feet into the gravel bed of the stream, the crest of the weir being 5 feet 6 inches above the grade of the canal. The total length of the weir is 80 feet from bank to bank.

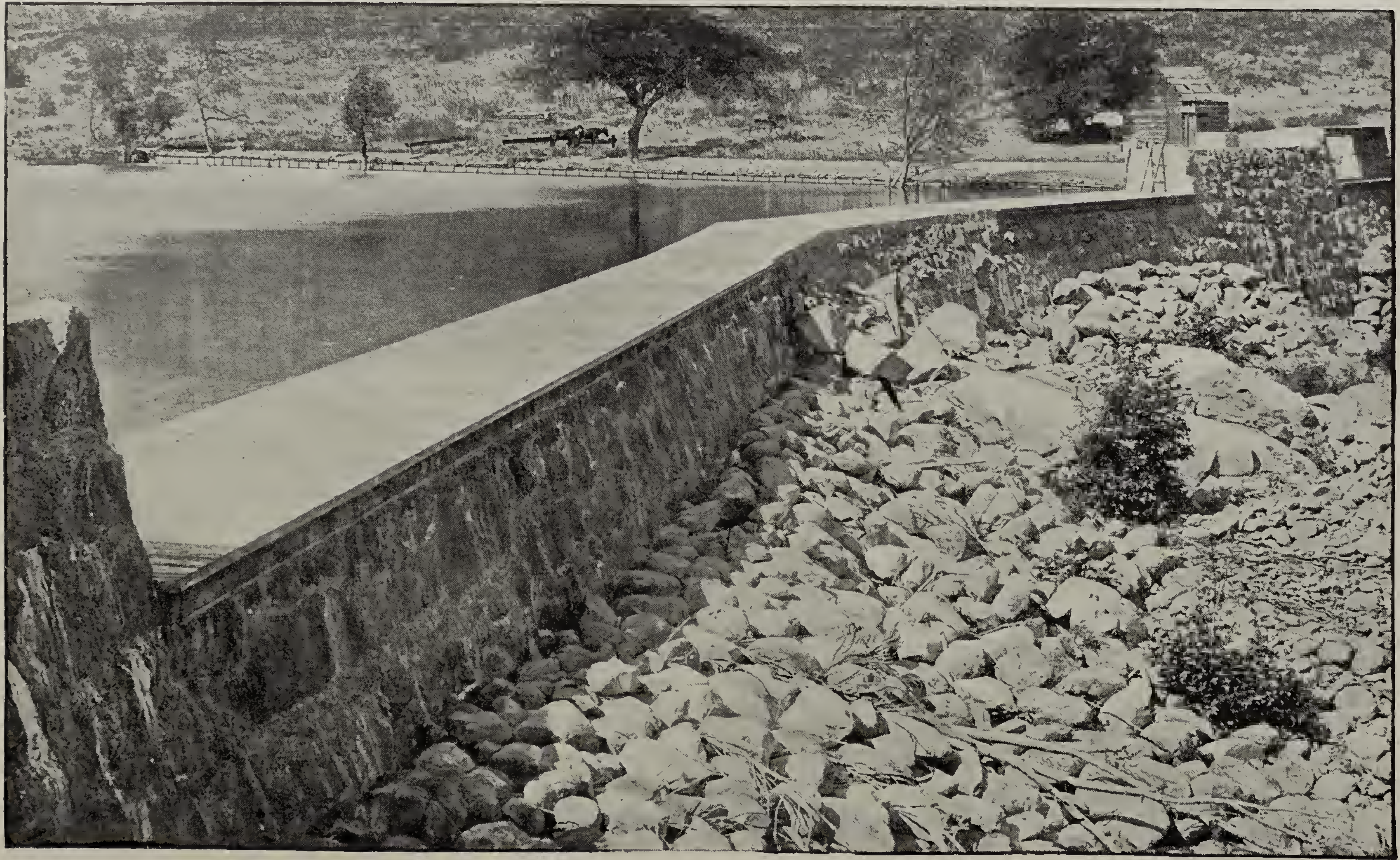
The Monte Vista weir (Fig. 90) gives a better idea of the form of construction of these weirs. It consists of an earth embankment, about 16 feet long, resting on the left bank of the river. Jutting into the stream at an angle with this is a crib dam, built essentially as is the open sluiceway, but filled in with rock. Beyond this and adjacent to the head regulating gates of the canal are a set of five open sluiceways, which can be filled in by flashboards. On top of the crib dam is a set of openings, 18 inches in height, likewise closed by flashboards, which thus increase the effective depth of the weir by that amount. This weir is founded on piles sunk 10 feet into the gravel bed of the river, and its crest is about 8 feet above the river bed.

COMPOSITE WEIR.

The weir at the head of the Arapahoe canal, Colorado, deserves mention in this place, not because of any peculiar merits in the mode of construction, but because it furnishes an interesting type of weir different from those described. This weir is thrown across Cherry creek and is 120 feet in length and 10 feet in maximum height above the bed of the river. It consists practically of a rectangular wall constructed by driving piles 6 feet apart between centers across the stream and 3 feet between centers longitudinally with the stream or across the section of the dam. These piles are 26 feet in length and in the center of the stream extend 16 feet below its bed. They are sheathed with 2-inch planking on either face and filled in with sand, forming practically a sand box. Through the central portion of this weir is constructed a wasteway 60 feet in length by lowering the top of the weir 3 feet, making its maximum depth here 7 feet and the remaining crest of the weir 3 feet higher. Ninety-six feet in length of this weir are constructed as above described; the remaining 54 feet in length adjacent to the left bank consists of a rubble masonry wall in which the head-gates of the canal are constructed. This masonry section is 3 feet wide on top, its outer slope being 2 on 1, the inner slope vertical. Its maximum depth to bed rock is 6 feet and its crest is on a level with the remainder of the weir.

MASONRY WEIRS.

The first diversion weir built in this country of solid masonry, the forerunner of the more substantial type of work now coming into vogue, is the diversion or pickup weir built across the San Diego river at the head of the San Diego flume. As shown in detail (Fig. 91) and illustrated on Pl. CXXV, this weir is built in two tangents, the exterior angle of which points up stream. Near its south end and extending out for a distance of 108 feet to the head or regulating gates which admit the water to the flume the cross section of this weir is 4 feet wide on top, or 1 foot less than that of the remainder of the weir. Beyond these regulating gates the weir is reinforced on its lower side by a great mass of loose rock, the object of which is to break the force of the falling water and protect the toe of the weir from undercutting. At a distance of 32 feet beyond the flume head is an open wasteway 20 feet wide, the crest of which is 4 feet lower than that of the remainder of the weir. For 14 feet beyond this wasteway, the weir is again given its usual height as far as a second wasteway, which is 165 feet in length,



SAN DIEGO FLUME. VIEW OF WEIR.

its crest, like that of the first described, being 4 feet lower than that of the remainder of the weir. The remaining 15 feet in length of the weir is again given the full height. Between the two wasteways just described and in the bottom of that portion of the weir which is built to the maximum height, also under the regulating gates at the head of the flume, are constructed two single undersluices, the gates of which slide vertically and are operated by means of a screw and hand lever from above. One of these undersluices has its sill 14 feet and the other 18 feet below the crest of the weir.

The cross section of this weir is peculiar and is the result to a certain extent of the failure on the part of its constructors to found it on bed rock. The first wall as originally built was 35 feet in height, 5 feet wide on top, and 16 feet wide at the base, and was sunk to a depth of from 15 to 25 feet into the gravel of the river bed, presumably to bed rock. It was soon discovered, however, that a considerable leakage passed under the weir, and after examination by competent engineers it was decided to build a sub-wall on the upstream side across the deepest part of the river channel as indicated. This wall is 16 feet in height, 4 feet in width on top, and 5 feet in width at its base, but it is claimed by those who were present during its construction that it was never carried all the way down to bed rock. This belief is exemplified by the fact that there appears to be considerable leakage under the weir and the discharge of the river below it is stated to be greater than it was before the weir was constructed.

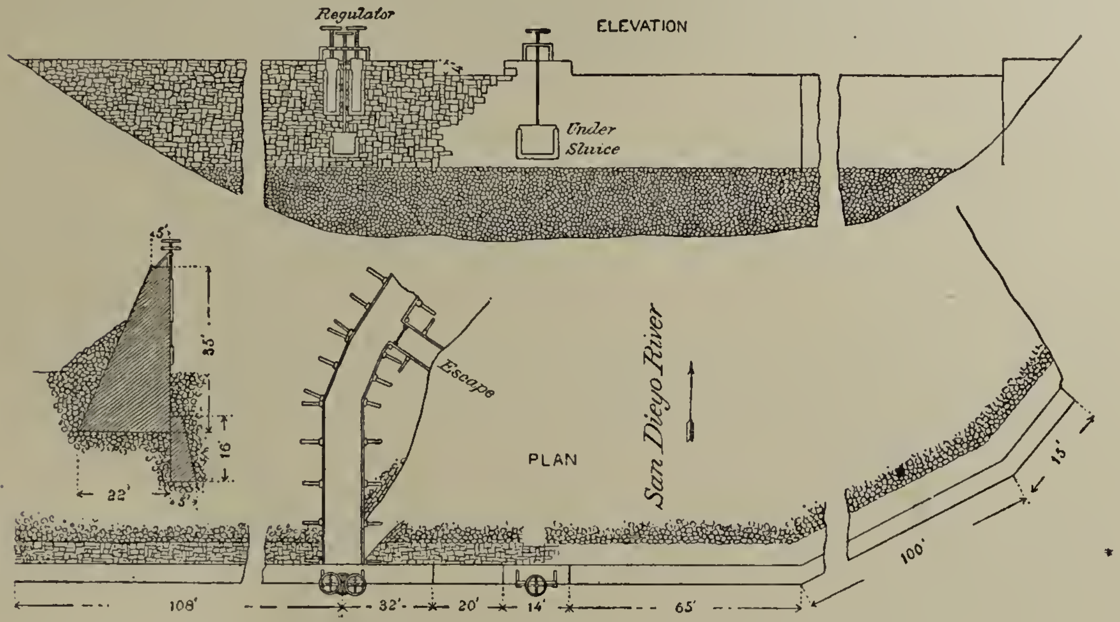


FIG. 91.—San Diego flume, plan, elevation, and cross section of weir.

One of the latest and most substantial and excellent diversion weirs constructed in this country is that built at the head of the Turlock and Modesto canals, across the Tuolumne river. This weir is located between high rock canyon walls at a point where its abutments and foundation are in a firm, homogeneous, dioritic rock in which scarcely any excavation was required for foundations. Over this weir the entire flood discharge of the Tuolumne river will pass to a maximum estimated depth of 16 feet. The work is constructed throughout of uncoursed rubble masonry in cement and has a length at its crest of 310 feet. As shown in cross section (Fig. 92), its maximum height is 130 feet, the maximum height of the overfall of water being 98 feet to a water cushion formed by a subsidiary masonry weir located at a point about 200 feet below the main weir in a narrow portion of the canyon. The main weir has a top width of 20 feet and is designed on a cross section somewhat similar to that of the Vyrnwy dam for the Liverpool water supply, its upper face being nearly vertical, while its lower face is given a curve similar to that which the water will assume in flowing over its face. Its maximum width at top is 12 feet, 5 feet of which are level, the inner 3 feet being given a circular curve with a 3-foot radius and the outer or lower edge being given with an 18·3-foot radius. The next 65 feet in length of the lower face is straight and has a slope nearly the same as a theoretical profile such as the Delocre or Bouvier formulas would give, while beyond this is a concave curve with a 30-foot radius, terminating in a convex curve with an 8·7-foot radius, followed by 8 feet on an easy slope. The maximum width of the weir at its base is 96 feet and it is dovetailed into the bed rock, forming its foundation by means of three great lugs or jogs filling trenches excavated in the rock. Its cross section is so designed that the maximum pressure on the toe when full will be 6·3 tons per square foot and is much heavier and more substantial than that which an ordinary masonry dam over which floods were not to pass would call for.

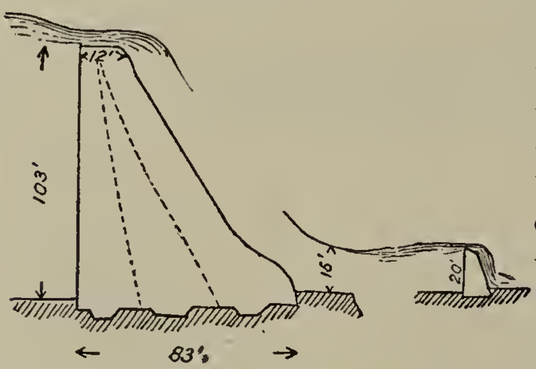
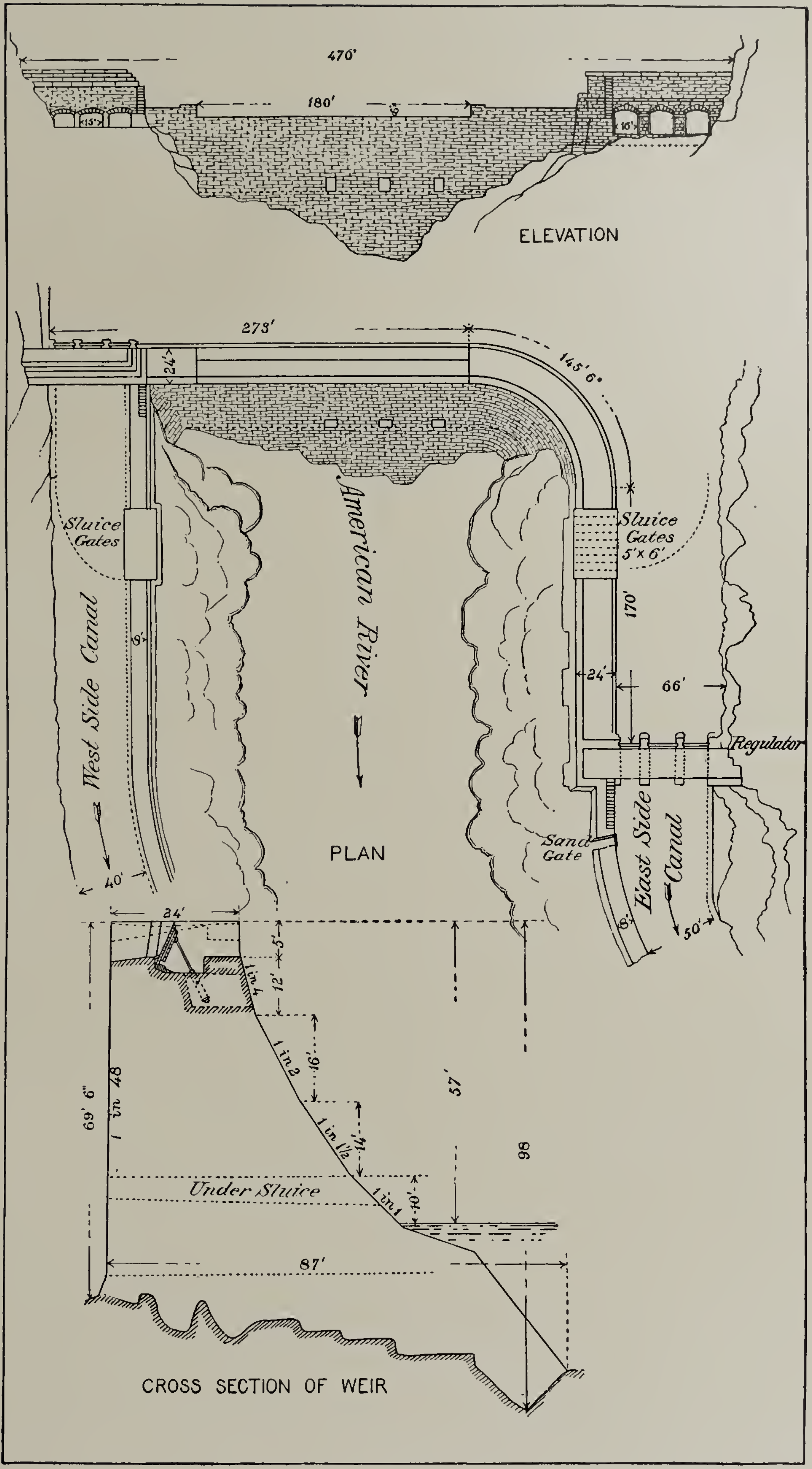


FIG. 92.—Turlock canal, cross section of weir.

The subsidiary weir, which is placed 200 feet below the main weir, is 120 feet long on top, 12 feet in width, and 20 feet in maximum height, and will back the water up to a depth of 15 feet on the toe of the main weir, giving a consequent water cushion of that depth into which the flood waters will fall, thus to a certain extent diminishing their shock.

The most substantial weir yet constructed in this country is that across the American river at the head of the Folsom canal. It was not built exclusively for purposes of irrigation, one of its main objects being the furnishing of water power for the State prison and for private uses at Folsom. This weir (Pl. CXXVI) is constructed of the best coursed granite rubble in cement, founded on firm bedrock and abutting against granite walls. The main tangent of the weir across the American river is 273 feet in length, while the first 250 feet of the canal on the left bank



FOLSOM CANAL. PLAN, CROSS SECTION, AND ELEVATION OF WEIR AND HEADWORKS.

reception in the top of the weir, and in them work the pistons which lift the gate. These jacks are fed from the power house by an hydraulic pressure of 1,000 pounds per square inch, and their power is such that they can raise or lower the great gate under a full head of water. The diameter of two of these hydraulic cylinders is 8½ inches outside, the piston which works within them having a diameter of 4⅝ inches and a stroke of 5 feet 6 inches. The remaining three cylinders are 11 inches in diameter outside and the pistons are 6 inches in diameter, the length of stroke being the same as those just described. The Pratt truss shutter which is operated by these cylinders is hinged to the piston of each hydraulic ram at about one-third of its length below the top, the center of the hinge being 2½ feet below the top. The maximum width of the shutter is 2 feet 5 inches, and it is braced vertically from top to bottom by 6 by 18 inch timbers placed 7 feet 6 inches apart between centers and trussed by iron rods. The hinges on which the hydraulic pistons work are 3½ inches in diameter, those at the base of the shutter being of nearly equal dimensions.

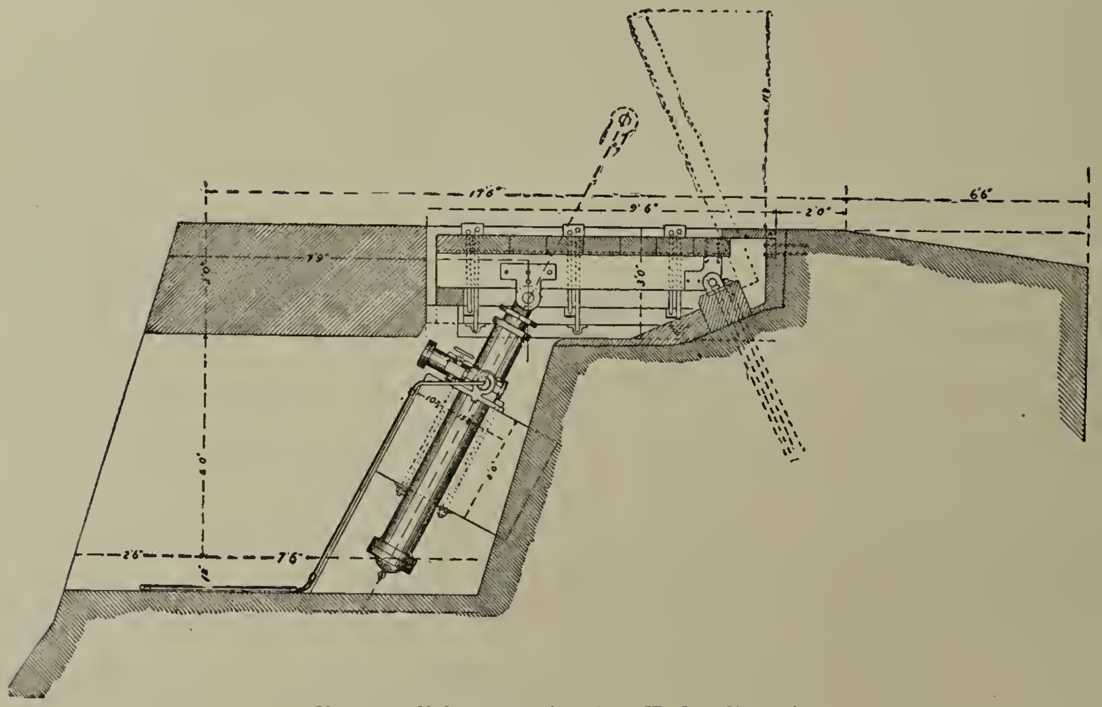
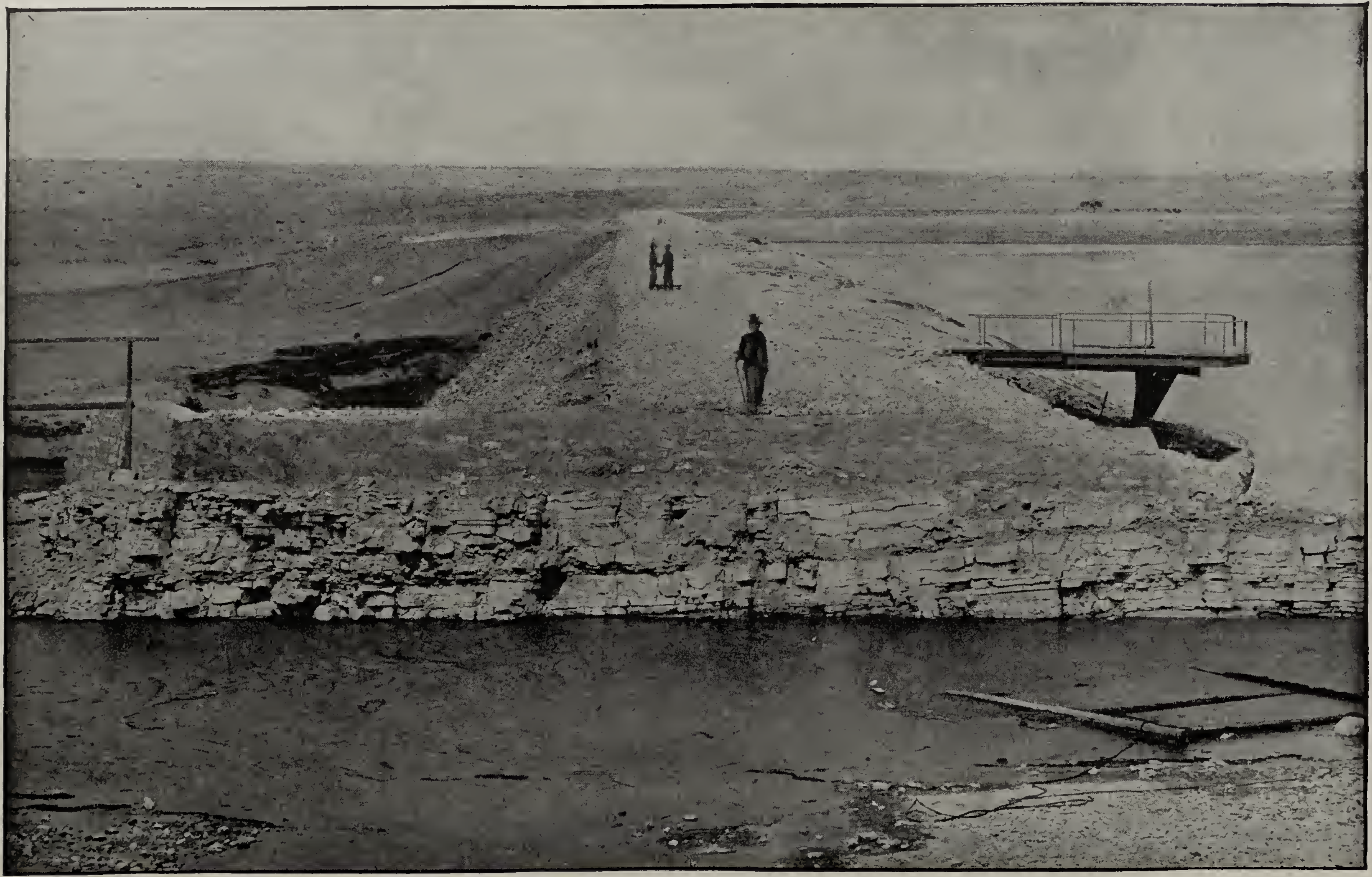


FIG. 93.—Folsom canal weir. Hydraulic jack.

DIVERSION DAMS.

Under the title of diversion weirs, the author has endeavored to describe only those structures which are so built that they can withstand the shock of the water passing over their crests. By diversion dams is meant such structures built for diversion rather than storage purposes, as it would be unsafe to permit water to pass over. Chief among these are earth, and combined earth and loose rock dams. Structures of earth alone are more usually built for water storage only as it would be eminently unwise to build them on flowing streams for purposes of



PECOS CANAL. VIEW OF DAM.

diversion. Dams of loose rock and earth combined have, however, been built for both purposes, and two are here described which have proven eminently satisfactory both for storing and diverting water.

An excellent example of a loose rock dam for storage and diversion purposes is that built across the Boise river at the head of the Idaho Mining and Irrigation Company's canal. The location of this dam and the adjacent head works of the canal are shown in plan on Fig. 78, B. From this it will be seen that the site for the dam is chosen where solid basalt outcrops the entire channel of the river, and on this the structure is founded. Just above the dam a basalt ledge, 12 feet in height, borders the river bank, and on this ledge is constructed the waste way which has a width of about 450 feet. This waste way is excavated in gravel, beginning at a point 344 feet above the north end of the dam, and the excavation is carried to a depth of 8 feet below the crest of the dam and is 720 feet in length, discharging back into the Boise river 100 feet below the main dam. In this wasteway is built a waste weir of rubble masonry across the entire width of the channel and founded on the basalt underlying the gravel. Its cross section is peculiar, as its base is about 19 feet in width parallel to the axis of the waste channel and 8 feet in maximum height. Its upper slope has a batter of 6 on 1, while its lower slope consists of an easy Ogee-shaped curve similar to that which the flowing water will assume. Opposite to the other end of the dam on the left bank of the river are constructed the head gates of the main canal. These, like the waste way just described, rest on a basalt ledge of equal height.

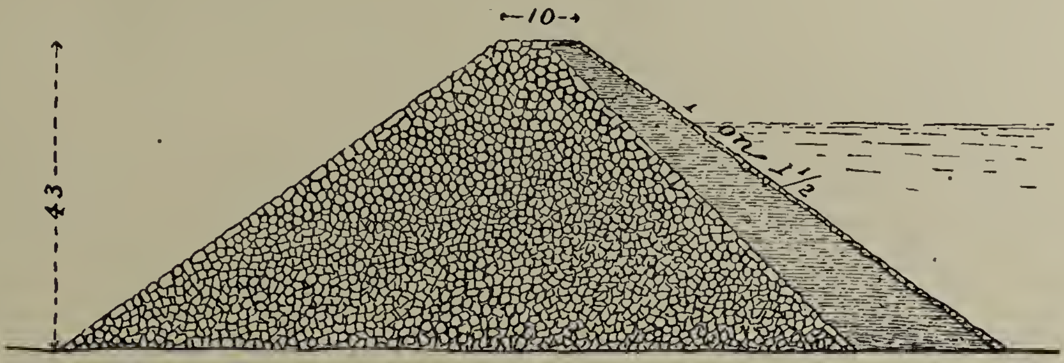


FIG. 94.—Idaho canal. Cross section of dam.

The main dam is constructed of loose rock with an earth facing. This dam is 220 feet in length on its crest and 43 feet in maximum height, its top width being 10 feet, of which 3 feet on the inner slope consist of earth facing, which at the bottom of the dam is 20 feet in width. The lower or rock face has a slope of 1½ on 1 and the upstream or earth slope the same. (Fig. 94.) As shown in elevation the dam is highest immediately adjacent to the canal head gates, where a small section about 10 feet in length is faced with a masonry retaining wall about 11½ feet in width at top and extending the whole depth. (Fig. 95.) This wall has a slope of 3 on 1, diminishing in width and height through the dam until it entirely disappears. This masonry wall is carried out, however, along the upper slope with a total length of nearly 70 feet, so as to form a wing which protects the dam from the action of the strong currents produced by the draw of the water into the canal head and scouring sluice. This latter is built in the masonry section of the dam immediately adjacent to the canal head, its object being the removal of silt from in front of the canal. The sill of this scouring sluice is 13 feet below that of the head gates and 34 feet below the crest of the dam. It is 4 feet in width inside and 8 feet high to the crown of the semicircular arch. At its entrance it is built in the solid masonry section of the dam just described, but as it passes through the dam this wall disappears, and the scouring sluice then consists of a masonry conduit 3 feet in thickness on top, increasing to 5 feet in thickness at the base. It discharges into the river just below the dam and is closed by a gate operated from the top of the dam.

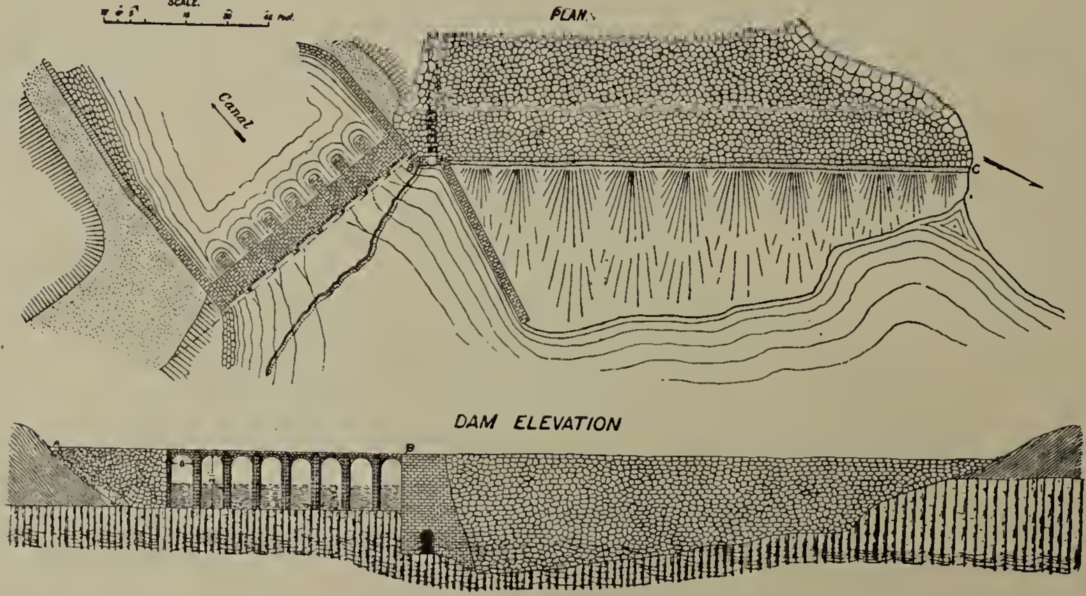
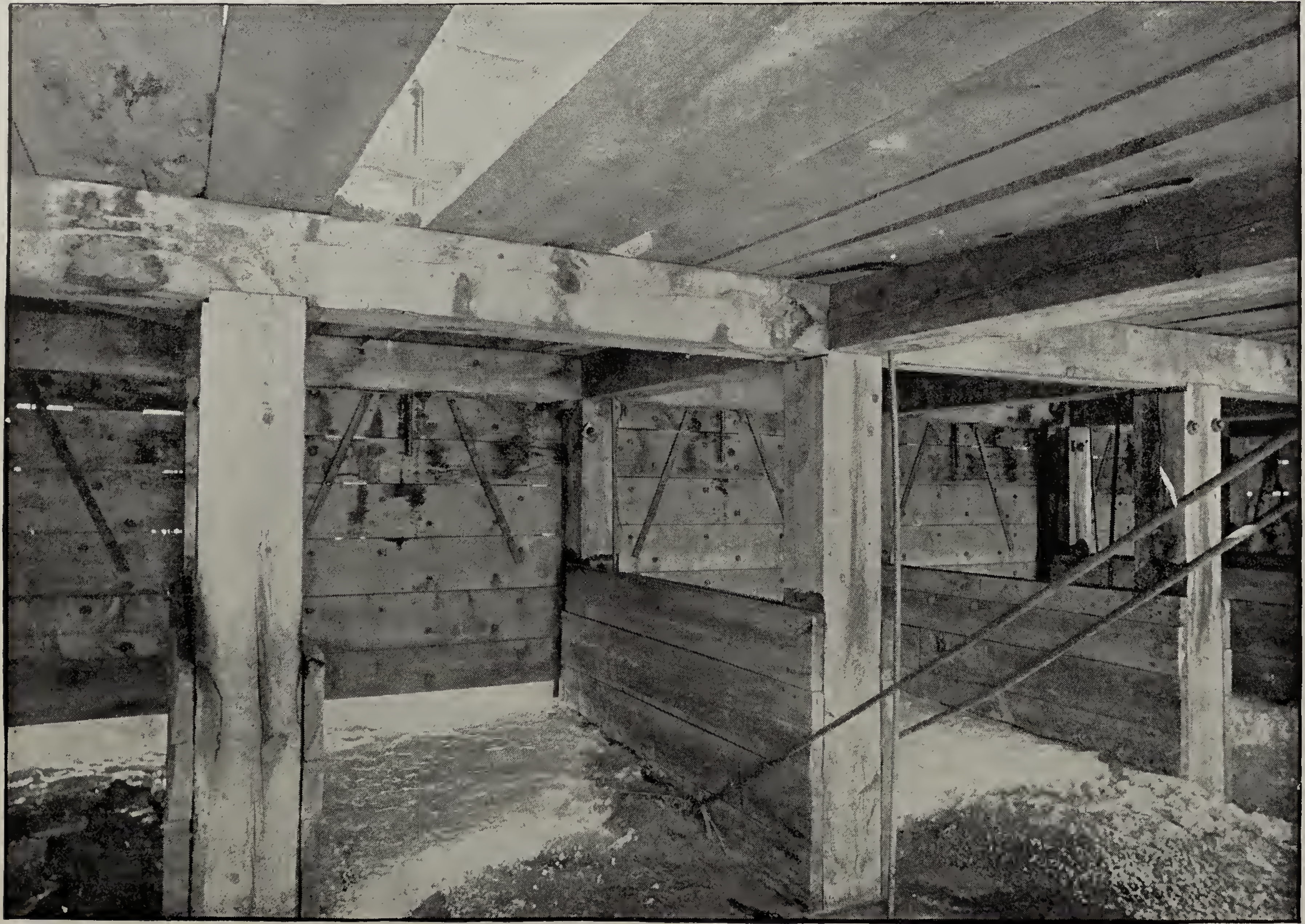


FIG. 95.—Idaho canal. Plan and elevation of headworks.

Another loose rock and earth dam and one well worthy of description is that across the Pecos river in New Mexico at the head of the Pecos canal. As shown in Fig. 96, this dam is shaped in plan like the letter L, the reentrant angle of which points upstream, the long arm abutting against the canal head. This long arm which composes the main dam is 1,070 feet in length and varies from 5 to 50 feet in height. The short arm consists of a simple earth embankment 530 feet in length with an average height of about 2 feet. Adjacent to the end of the dam which is farthest from the headgates is constructed an ample wasteway 256 feet wide, excavated in the limestone rock to such a depth that its bed is about 5 feet below the crest of the dam. This wasteway is 300 feet long and has a grade of 1 in 3. For greater security and certainty of action it should be deepened somewhat. In the rock cut on the left bank of the river is an additional wasteway just



DEL NORTE CANAL. VIEW OF REGULATOR FROM INSIDE.

below the end of the dam and above the regulating gates. This wasteway has a total length of 206 feet and is about 2 feet deeper than the one just mentioned. It accordingly comes first into action and between the two the dam may be considered perfectly safe from any possible flood.

The main dam (Pl. CXXVII) is composed of a prism of loose rock 12 feet wide on top, 100 feet wide at the bottom with a lower or outer slope of 1 on 1½ and an inner slope of 4 on 1. Its maximum height is 50 feet and the upstream face is backed with earth, the width of this backing being 10 feet at top, 200 feet at the bottom, while its upstream slope is 1 on 3½ and is faced with 18 inches of stone paving to protect it against wave action. (Fig. 97.) The lower portion or toe of this slope is replaced by 10 feet in depth of loose rock for a total width through the dam of 75 feet, to prevent undercutting by currents. This dam is substantially built, all of the rock being hand-placed, while the earth was well tramped over with scrapers. Owing to a miscalculation made at the time of building, it was found that the top width of the structure would be less than was deemed desirable; accordingly a masonry wall 6 feet in height and 2 feet in width and rectangular in cross section was built into the downstream face on top of the loose rock section. This wall is built of ordinary lime mortar, but as it will not be subject to the action of water it is considered sufficiently substantial to perform its duties. With the addition of this wall the total width on top of the dam is 24 feet, consisting of 10 feet top width of earth, 12 feet

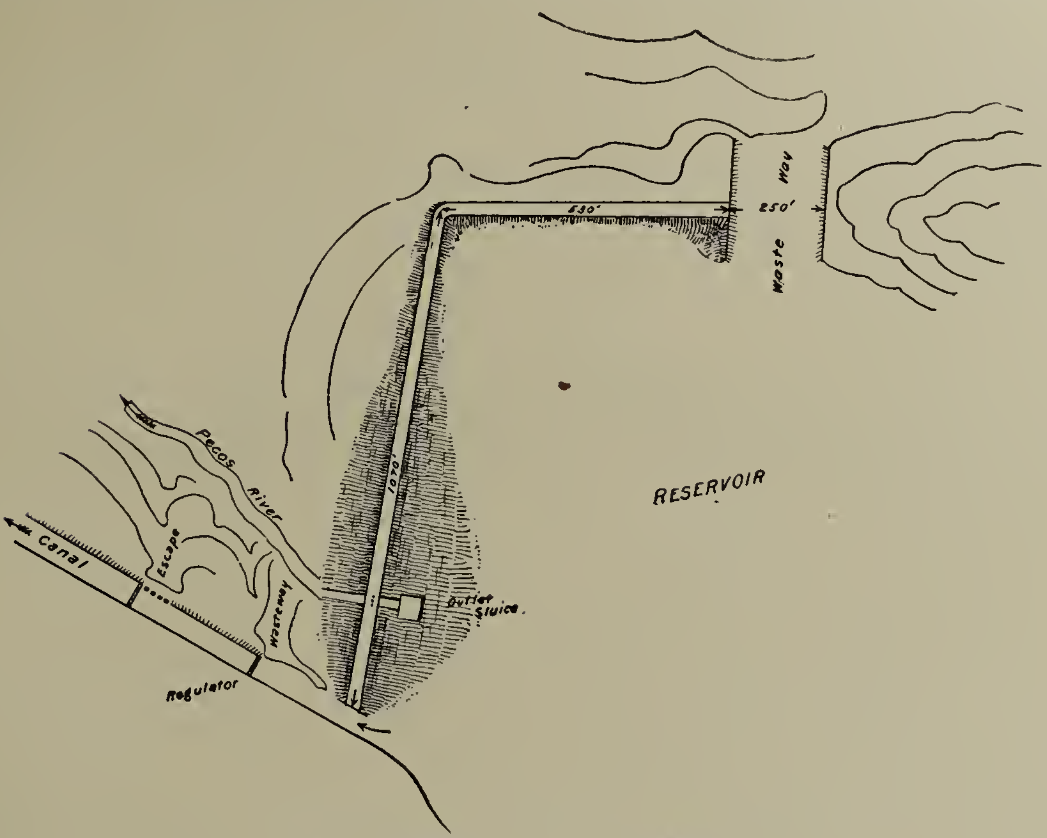


FIG. 96.—Pecos canal. Plan of headworks.

top width of loose rock and 2 feet in width of masonry retaining wall. In the bottom of the dam, near the end adjacent to the canal head, is an undersluice the sill of which is 37 feet below the dam crest. This sluice is 4 by 8 feet in the clear and has a grade of 1·2 feet in 100, its discharging capacity with the reservoir full being about 2,000 second-feet. The lining of the culvert composing the undersluice is of rubble masonry and is 8 feet in thickness.

REGULATORS.

There are four essential parts composing the works of every large canal. These are the weir, by means of which the water in the stream is raised to a sufficient height to pass into the canal head; the scouring sluices, which in American construction form usually a part of the weir; the regulator, which is placed immediately within the entrance of the canal, and consists of a series of gates for the control of the water admitted to the canal; and lastly the wasteway or escape, which is usually built in the side of the canal a short distance below the regulator.

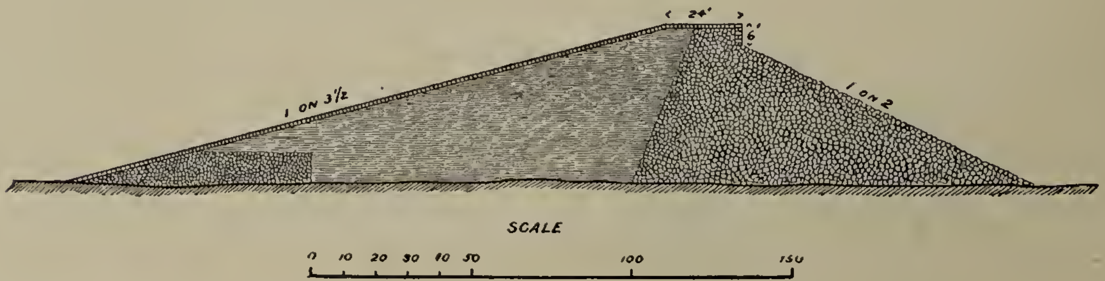
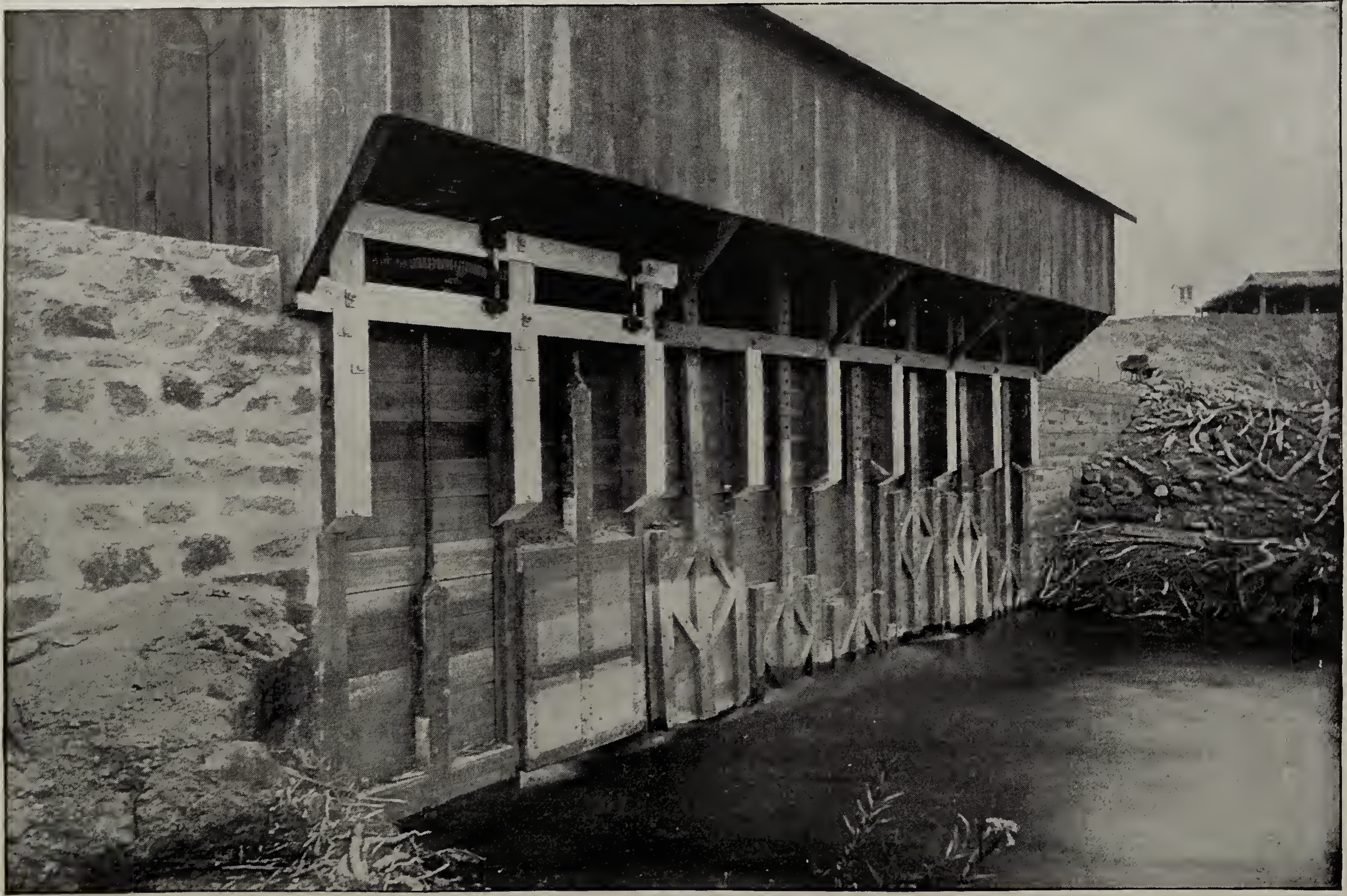


FIG. 97.—Pecos canal; cross section of dam.

Like the other parts of American canals, regulators have gone through a series of progressive improvements, from the simple horizontal wooden flash boards which are dropped into grooves in uprights, such as those used on the Calloway canal, to the elaborate and perfect mechanical contrivances used to operate the steel gates at the head of the Folsom canal. Intermediate between these two extremes we find plain wooden gates sliding between wooden bearing posts lifted by hand levers, and other gates of similar construction raised by means of a windlass or hand screw operated from above.

Much good judgment may be exercised in the location of these regulating gates according to the material composing the soil and the velocity of the stream from which the canal is diverted as well as the angle at which it must take off. These gates may be immediately adjacent to the weir, or may be set back in the canal some distance from its entrance. An excellent example of this latter case is that of the head of the Central District canal in California. This relation of regulator to weir is generally so established that the canal shall receive the desired volume of water and that there shall be the least liability to silt in front of its gates. The head of the Arizona



ARIZONA CANAL. VIEW OF REGULATOR GATES.

canal has been so located and arranged that silting has taken place in front of the regulating gates to such an extent that it is impossible for the volume of water necessary to fill the canal to enter them. A large amount of silting has occurred at the head of the Calloway canal, owing to the bad angle at which it is diverted from the river; while in the case of the Pecos canal, the regulators of which are placed back of the weir some distance in a deep rock cut, the slope of this and the scour caused at the head by a wasteway are such as to prevent any deposit of silt.

The regulator at the head of the Calloway canal is of the simplest form of construction. It is of the same design and built in the same manner as the weir at the head of this canal, which is described on page 170. The only difference is in the abutments, which are constructed of horizontal 8 by 1 inch plank, and retained by light 4 by 6 inch uprights, each 9 feet in height and topped by a cap piece 6 by 4 inches spiked to them. The uprights and cap piece are tied in the bank to anchor piles. These uprights are 2 feet apart, resting on the joists. The regulator is built as a straight continuation of the weir (Fig. 67, B), from which it is separated by a narrow neck of land protected by the abutment just described. The total width of the regulator opening is 100 feet, divided into 25 bays each 4 feet wide. The plank on this floor is 2 inches in thickness, and the bays are opened or closed by means of inserting flashboards. As stated on page 171, the crest of these regulating gates is 11 feet above the floor, or 1 foot higher than the weir crest.

Another very simple form of regulating gate is that used at the head of the Wyoming Development Company's canal, or the one which is placed at the head of the Merced Reservoir Supply canal. This latter is practically an open wooden flume, floored for 10 feet upstream and 20 feet downstream from the gates, and it consists of 3 inches in thickness of planking laid on floor beams, which run crosswise of the canal channel and rest on mudsills laid lengthwise. As a result of this arrangement the floor boards are placed lengthwise or parallel to the current. Anchor and sheet piling is let 4 inches into the rock on either bank and cemented there. The gates are placed with the vertical face upstream and rest against simple wooden upright beams of 6 by 8 scantling, which latter is braced downstream by means of struts or knees resting on the bottom of the flume. These gates are simple wooden frames, closed by boarding them over, and from the top of which rises a central upright or scantling running between guide rails laid overhead. In these uprights are holes, so that the gate may be raised by hand levers inserted into these. Back of the flume-like abutment forming the sides of the gateway wooden wings run for 20 feet and are braced into the earth by anchor piles. Simple wooden pawls are pressed by the action of gravity into notches let into the sides of the upright, and by this means the gate is suspended at any desired height.

The regulating gates at the head of the Del Norte canal are simple and effective in construction. The regulator is set back in the canal some distance from the entrance cut (Fig. 68, B); opposite and in front of the weir is a wooden fence or fender, the object of which is to stop floating driftwood. The regulator is built between rock walls and on the rock foundation in the canyon at the canal head, and consists of the usual wooden flume or box (Pl. CXXVIII). It has 59 feet 6 inches of clear opening controlled by 10 gates, each of which is 9 feet in height. These gates are of wood, well braced, and they slide between upright wooden posts, placed about 7 feet apart. The regulator is properly a regulating bridge, as across the top of the gates is built a wooden bridge, from which they are operated. The machinery for raising or lowering the gates consists of a 1⅝-inch upright iron bar, on which is turned a screw thread, and this works into a female screw attached to the upper rail of the bridge and worked by means of a handwheel. (Fig. 98.)

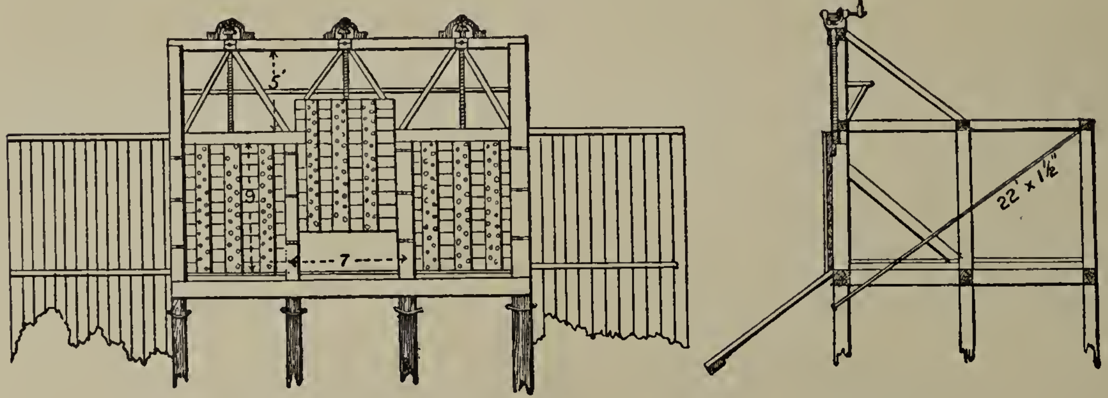
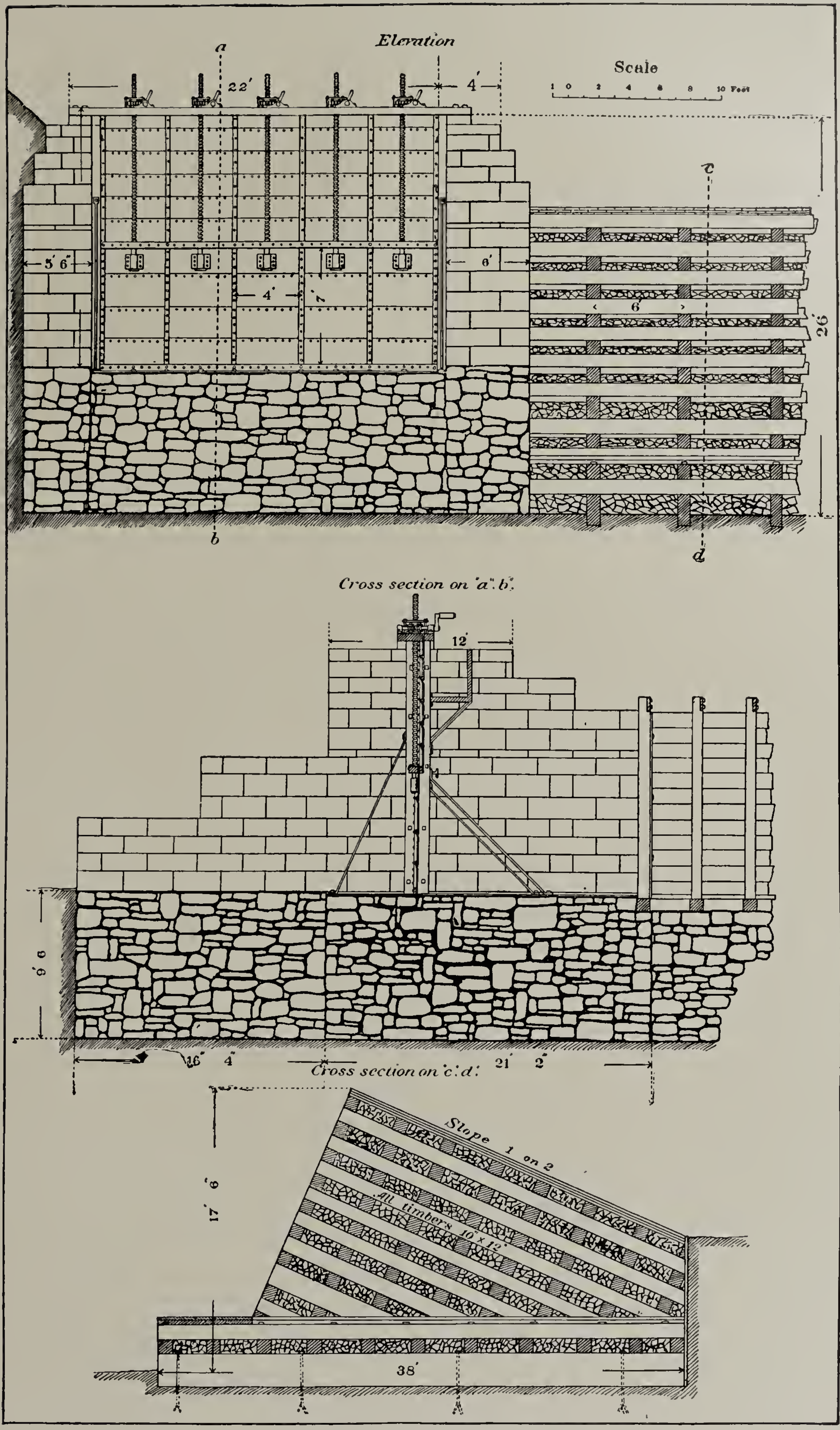


FIG. 98.—Del Norte canal. Elevation and cross section of regulator gates.

The regulator at the head of the Arizona canal is very similar in construction to that at the head of the Del Norte canal. Owing to the fact that the weir crosses the river diagonally and the fact that the canal is taken off in a course nearly parallel to that of the river (Pl. CXIII, B), the waters of the latter in times of flood impinge against the regulator head with great force. Adjacent to the head and between it and the weir are a set of seven scouring sluices, introduced with the object of preventing deposits of silt at the head. That they have been ineffectual is shown by the large island formed in front of the head, the result of the deposit at this point. The present regulator gates are shown in detail on Pl. CXXIX, which is a view taken from the upstream side. From this it will be seen that the regulator consists of eight gates, which slide vertically between wooden uprights, and are operated from a covered bridge which passes overhead. Six of these gates are raised by means of a lever inserted into holes in the upright above them, while two are meant to be used when the pressure of the water is great and can be raised to a height of 6 feet, while the total height of the headworks and the adjacent abutments is 17 feet, thus giving a large headway through which the flood waters of the river may pass. The two high-pressure



BEAR RIVER CANAL. ELEVATION AND CROSS SECTIONS OF WEIR AND REGULATOR.

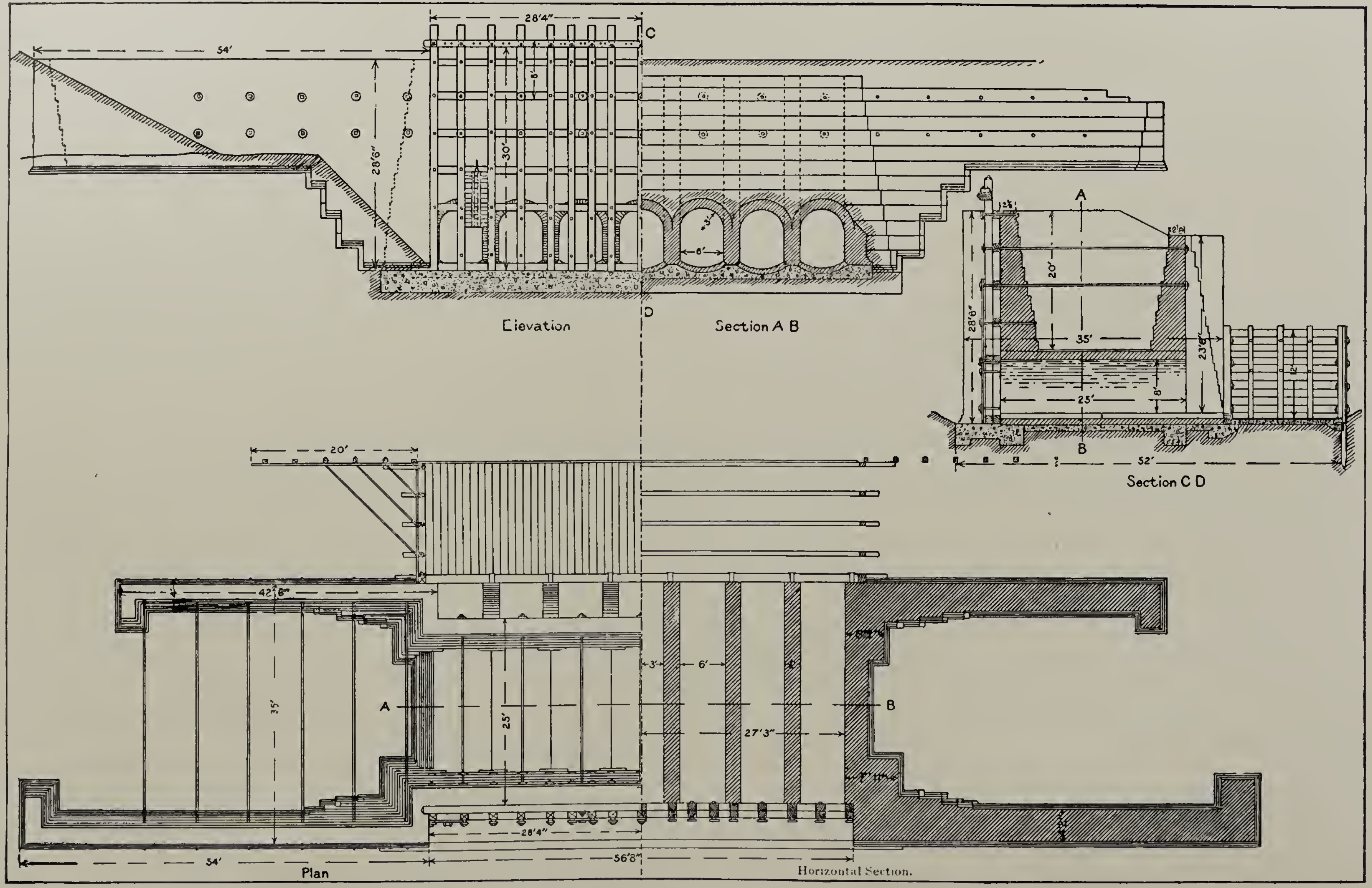
gates are worked by an ingenious and simple contrivance. Rising from their tops and attached to the wooden framing is a heavy iron screw, which works in a female screw, forming the inner circumference of a geared cogwheel. This latter wheel is turned by means of a hand gear and can be operated under the greatest head of pressure which may occur at this point.

The regulators at the head of the Bear river canal are more substantial in character than any of those previously described. The West Side canal heads in a rock cut in which is built a length of 50 feet of wooden flume, or rather a wooden retaining wall. The bottom of this flume consists of the rock in which the excavation is made, while the top is open and braced across by horizontal timbers supporting two wooden wing-walls. For 16 feet at either end of this flume or regulator head the floor inclines up and down stream with an easy grade to a depth of 3 feet below the sill of the gate. Puddled earth is put in behind the wooden wings between it and the rock wall of the excavation, and the flume is calked throughout with oakum. The work is substantially set in masonry and cut stone (Pl. CXXX), and the gates, which are five in number, are raised and lowered by means of screws and hand gearing.

The arrangement of the headworks at the entrance of the Pecos canal is shown in plan in Fig. 96. As will be seen, the regulating gates are set back in a deep rock cut some distance from the entrance, which is 30 feet in width and 30 feet in maximum depth. This cut is 850 feet in length, and has a steep grade, thus causing the water to flow through it with considerable velocity. Immediately below the entrance cut and adjacent to the left abutment of the dam is an escape way excavated from this cut, and having a total width of 206 feet. At the lower end of this wasteway, which discharges immediately back into the river, are placed the regulating gates, six in number, and confined between the solid rock walls of the cut. These gates are of wood, and are separated by wooden piers. The total height of the regulator from the sill to the crest is equal to that of the cut, thus giving to the reservoir a maximum available depth of about 25 feet. The regulating gates are 5 feet in width and 9 feet in height in the clear, and are worked from above by means of a male screw attached to the gate, on which a female screw is worked from above by means of a simple hand-wheel. The male screw is of hard steel, while the female screw is of malleable iron, thus permitting it to take all of the wear. The upright posts separating the gates are of 12 by 12 beams, and the wooden gates are very stoutly constructed and are 6 inches in thickness. The total velocity of this regulator under a full head of pressure is 3,000 second-feet.

Below this first regulating gate the water flows on through the rock cut to a second or subsidiary regulator constructed across the canal, immediately above which is a second escape way having a total width of 70 feet. This lower escape is divided into ten openings of 7 feet each by means of upright wooden posts 4 feet in height, between which wooden flashboards can be inserted so as to force all of the water into the canal if necessary, or, if these flashboards are removed, the water will fall a total height of 26 feet over a masonry wall onto solid rock below, whence it runs back to the river. The second or lower set of regulating gates are four in number and are constructed of wood, each 3 feet high by 12 feet in length and are of 4-inch planking, thus giving them an escape way equal to that of the canal at this point, 48 feet in total width. These gates are hinged at the top to a substantial overhead beam and swing upward, being opened by means of a crane only when the upper regulator is closed, so that there is no water pressing above them. They are closed by simply dropping them, their own weight carrying them down.

The headworks of the Central Irrigation canal in California are unique in general design owing to the peculiar topography of the banks of the Sacramento river at the point of diversion. At this point the Sacramento river flows through land which is a trifle higher than some of the country immediately adjacent to it and as a consequence the canal heads from the river practically as do the inundation canals of the Indus valley in India head from that river. It was found simply necessary to make a straight cut out of the Sacramento river without constructing any dam or diversion work in the stream to turn the water into the cut. This was largely due to the fact that the perennial discharge of the stream was more than sufficient to supply the wants of the canal. The bed of the canal at this point is from 1 to 2 feet below low-water level. The regulator at the head of the canal consists practically of two parts—a main set of masonry headgates set back in the cut one-third of a mile from the river bank, and a secondary set of regulating gates and a waste gate set back 3 miles farther. There is no pressure to be neutralized on the first set of masonry gates since water can be held up by the second set in such a manner as to equalize the pressure on both sides of the first set of gates, thus relieving them of this pressure and permitting them to be raised by a simple contrivance consisting of a hand gearing and screw. The lower or secondary set of regulating gates are constructed of timber weighted with earth and opposite them is an escape which conducts surplus waters back into the Sacramento river. This second set of gates can likewise be operated without the pressure of water against them and are closed by a simple set of flashboards. The total height of the second set of regulating gates above the canal bed is 24 feet, while the first set of gates is 26·8 feet in height above the canal grade and to this elevation the floods of the river occasionally rise. As shown in plan and elevation in Pl. CXXXI, the main regulator consists of seven openings or masonry tunnels each 6 feet in width and about 8 feet in height curved both above and below. These are founded on a thick bed of concrete and are sepa-



CENTRAL IRRIGATION DISTRICT CANAL. PLAN AND ELEVATION OF REGULATOR.

rated by masonry walls 25 inches in thickness, while the abutments and wings of the regulator consist of solid masses of masonry extending well back into the sides of the canal cut. In front of these openings is erected a gridiron work of timber, the total height of the framing being a little over 30 feet. Between these frames slide the gates, which are of wood and are operated from an overhead bridge. These gates are 4 inches in thickness and are well braced by longitudinal wooden scantling.

The regulator at the head of the Idaho canal is represented in plan and elevation in Fig. 95, and is both unique and substantial in construction. This regulator consists of 8 openings each 8 feet wide and 19 feet high in the clear to the crown of the curved arch which surmounts them. They are constructed of substantial masonry in cement, surmounted by a bridge, the height of which is 21 feet above the lava bench on which the sill of the gates rest for 33 feet above the river bed. The masonry piers separating the openings are 3 feet in thickness, their faces being vertical on the upstream side and for 6 feet from the down stream side, below which they are given a batter of $\frac{2}{3}$ to 1. The gates which close these openings are constructed on a model somewhat similar to those employed by the French Government in the weirs designed to give slackwater navigation on the river Seine. Their unusual size is necessary for the convenient admission of timber and floating wood, which renders it impossible to use the ordinary sliding gate. This gate (Fig. 99) consists of a roller curtain composed of steel plates and angle iron to a height of 10 feet, from the base above which it is constructed of pine slats, each 6 inches wide. There are twenty of these slats constructed of steel and eight of wood, and the bottom of the curtain is fastened to a cast-iron roller, on which it is wound up from above in the form of a spiral by means of a single chain operated from the overhead bridge by a winch. All the hinges on this are of bronze.

There are three sets of regulating gates at the head of the east and west side Folsom canals, each of which are constructed on practically the same design. Those at the head of the East Side canal are already built, and therefore will be described here. These headgates are 170 feet below the lower end of the dam and about 100 feet below the upper set of sand gates which were described elsewhere. They are constructed in the most substantial manner of granite masonry, and have a total width of 66 feet between abutments. These latter are of granite masonry built into the rock walls of the canyon on one side and supported by the masonry retaining wall on the other. Their general design and details are shown in Pl. CXXXIII, while the view on Pl. CXXXII gives an excellent idea of the manner in which they are built. The gates in this regulator are three in number, each 16 feet in width and 14 feet in height to the crest of a semicircular arch. They are separated by masonry piers 6 feet in thickness, and their total height from the sill of the canal to the crest of the masonry work surrounding the regulator is 37 feet. The masonry in which these regulators are built is 22 feet in least thickness, while the pilasters separating the gates increase their total thickness to 31 feet. The gates which close the regulator are of wood, well braced, and slide vertically in grooves let into the masonry piers separating them. They are raised as are the sand gates and the big shutter on the top of the weir, by means of hydraulic jacks operated from the State power house. These jacks are three in number, one to each gate, and are firmly fastened to the masonry above the gate. They consist of iron cylinders in which work steel plungers having a 14-foot stroke.

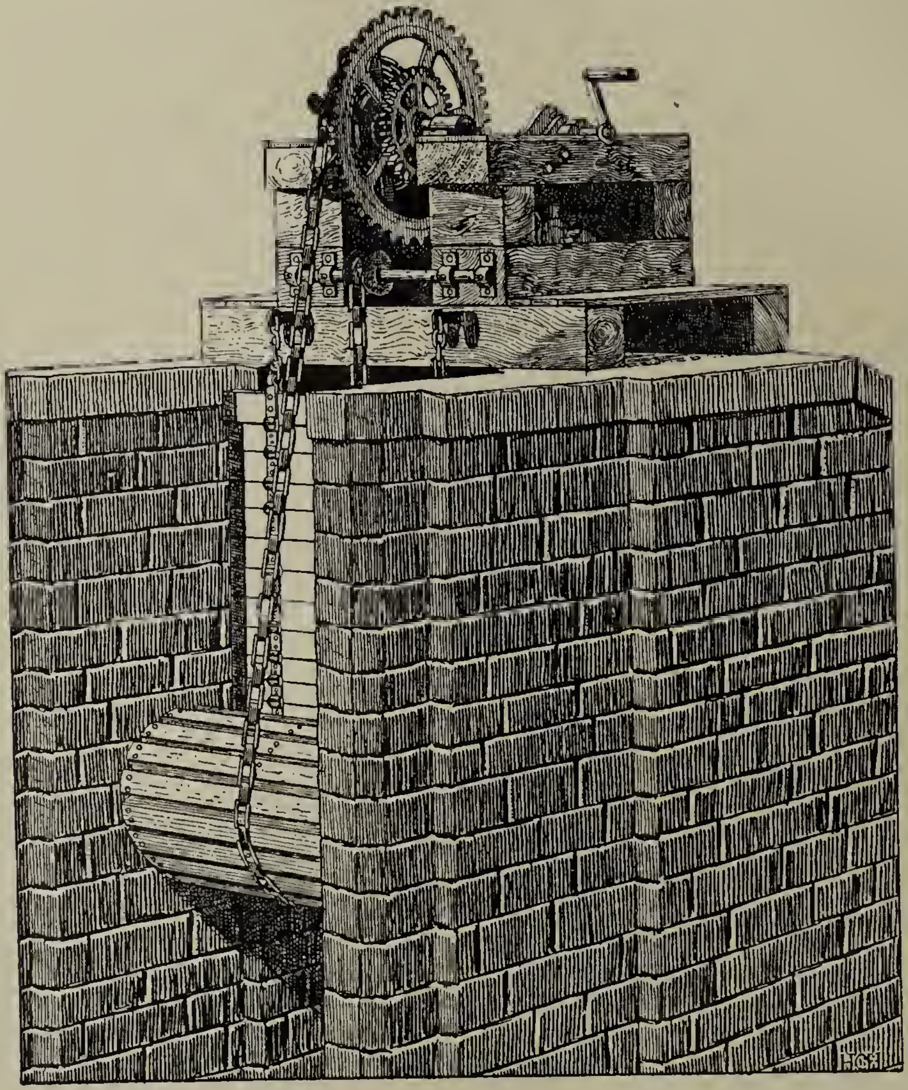
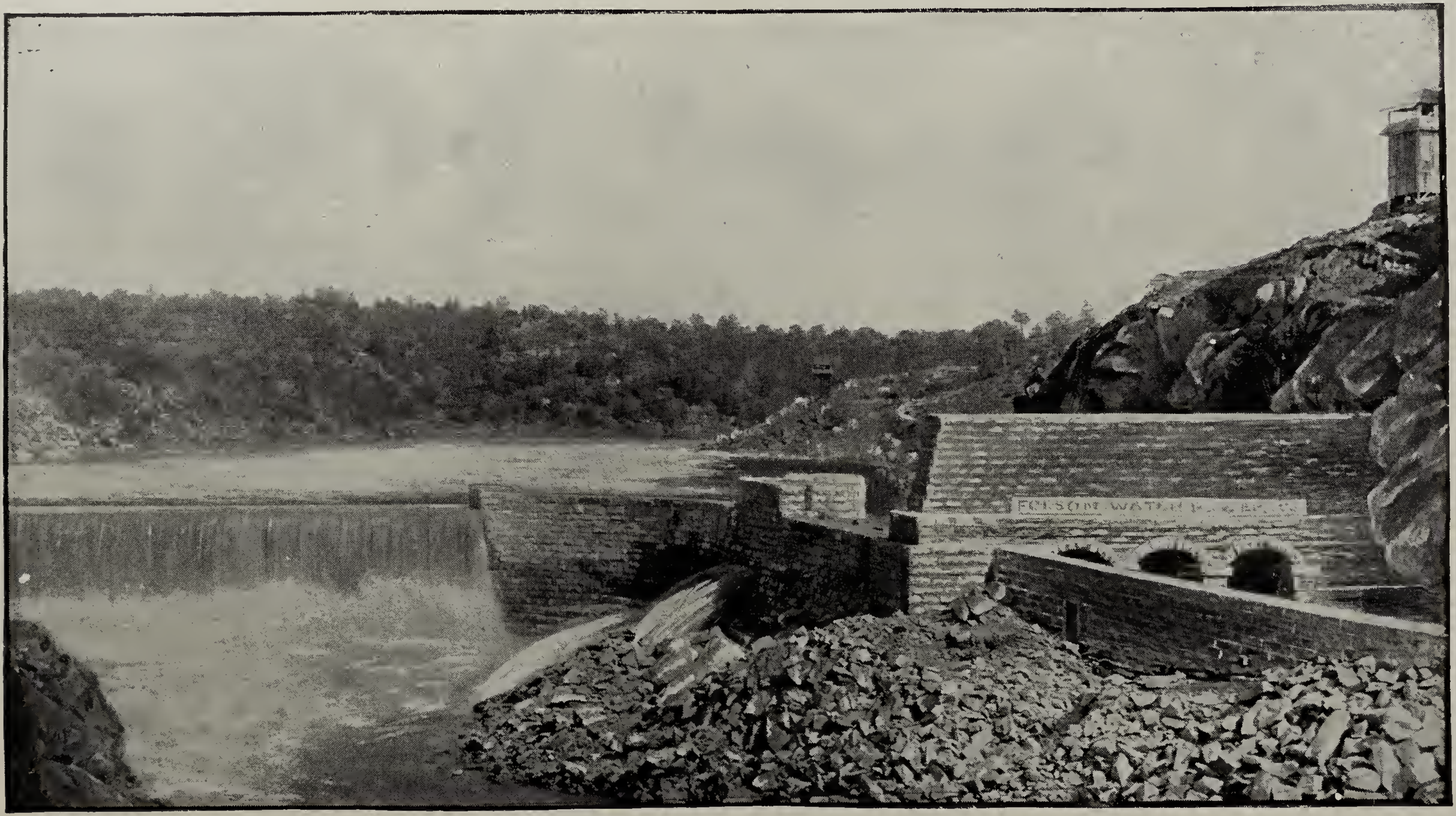


FIG. 99.—Idaho canal. View of rolling regulator gate.

ESCAPES.

Escapes should be provided at certain intervals along the entire length of every canal in order that a complete control may be had over the water in its channel. This control is obtained by the escapes affording a means of disposing of any excess of water which may occur in the



FOLSOM CANAL. VIEW OF WEIR AND REGULATOR.

canals due to sudden rains or floods or to the water not being required for irrigation. The first escape should always be placed within a quarter of a mile of the regulator in order that in case of breakage or accident the water may be immediately drawn from the canal, especially if the regulator fails to work. This upper escape has the additional advantage in the case of streams which carry much sediment in suspension of flushing the canal, thus preventing or removing excessive deposits of silt.

Escapes may be placed at varying distances along the line of the canal. It is usual to place them at distances not exceeding 15 miles, though in the case of long lines of canal they may be 20 miles apart, and they are also provided at dangerous points on the canal, as on flumes or aqueducts which cross streams, above heavy embankments, and in other similar places. The escape consists of a row of gates similar to the gates of the regulator, let into the banks of the canal and discharging immediately into a cut or natural water channel which leads the water off to some main drainage line. This escape-cut or channel should be sufficiently large and have sufficient grade to carry off the whole body of water which may reach it from both directions, in order that if necessary the canal may be emptied in the shortest possible space of time. Complete control of the water in the canal is had by building a set of regulating gates immediately below the escape head so that the channel below this regulating gate may be left entirely dry. In many canals, owing to the location of the head regulator, it is necessary to introduce an escape immediately above this regulator, in order to relieve the canal of any surplus water which it may be necessary to pass through the regulating gates.

Like the regulating gates, the escapes on the American canals have been constructed of many designs and of many degrees of permanency. Among the simpler forms are the plain wooden flashboard gates such as are used on the Calloway canal. More substantial and permanent are the solid wooden gates which are raised vertically by means of screws, such as those employed on the Bear river and Central District canals. Other escapes are through cylindrical pipes, such as those used on the Idaho canal, while there are substantial masonry escapes, such as those employed on the Folsom canal. But brief descriptions will be necessary in the case of any of these, owing to the similarity between their form of construction and that of the regulating gates.

The first main escape on the course of the Highline canal in Colorado is at the lower end of the tunnel, 600 feet below the head regulators, and it consists of a set of four wooden gates each 3 by 4 feet, set into the side of the bench flume and raised by a simple rack and pinion. In the flume opposite and below these escapes are a set of checks or flashboards 2 feet in height, which slide vertically between grooves set in posts across the channel of the flume. By removing or replacing these flashboards the water of the canal can be permitted to flow on down the flume or can be turned through the escape back into the river. This escape is shown in the foreground in the illustration on Pl. CXXXV. In addition to this first main escape there are several others placed at various intervals along the line of the canal, one at the crossing of Willow creek and another in the flume across Plum creek.

A great weakness in the design of the Arizona canal is the lack of escapes. There is only one escape provided along the entire line of this canal, though in practice the cross-cut which serves the Consolidated and Grand river canals from the main canal acts as an escape. About a mile below the regulating head is the first and only true escape on this canal, and below this escape is a set of regulating gates placed across the channel of the canal in order to turn the water through the escape. This escape is constructed of timber, and is closed by seven gates, as shown in Fig. 100. These are simple rectangular gates, sliding vertically between upright wooden posts, and are raised by means of a hand lever working in holes in the tops of the gate posts. The whole of this work rests upon piles capped by stringers and is well floored, while the banks of the canal are protected by stout wooden wings. The escape gates have a total width of 40 feet and a length of wooden fluming or channel

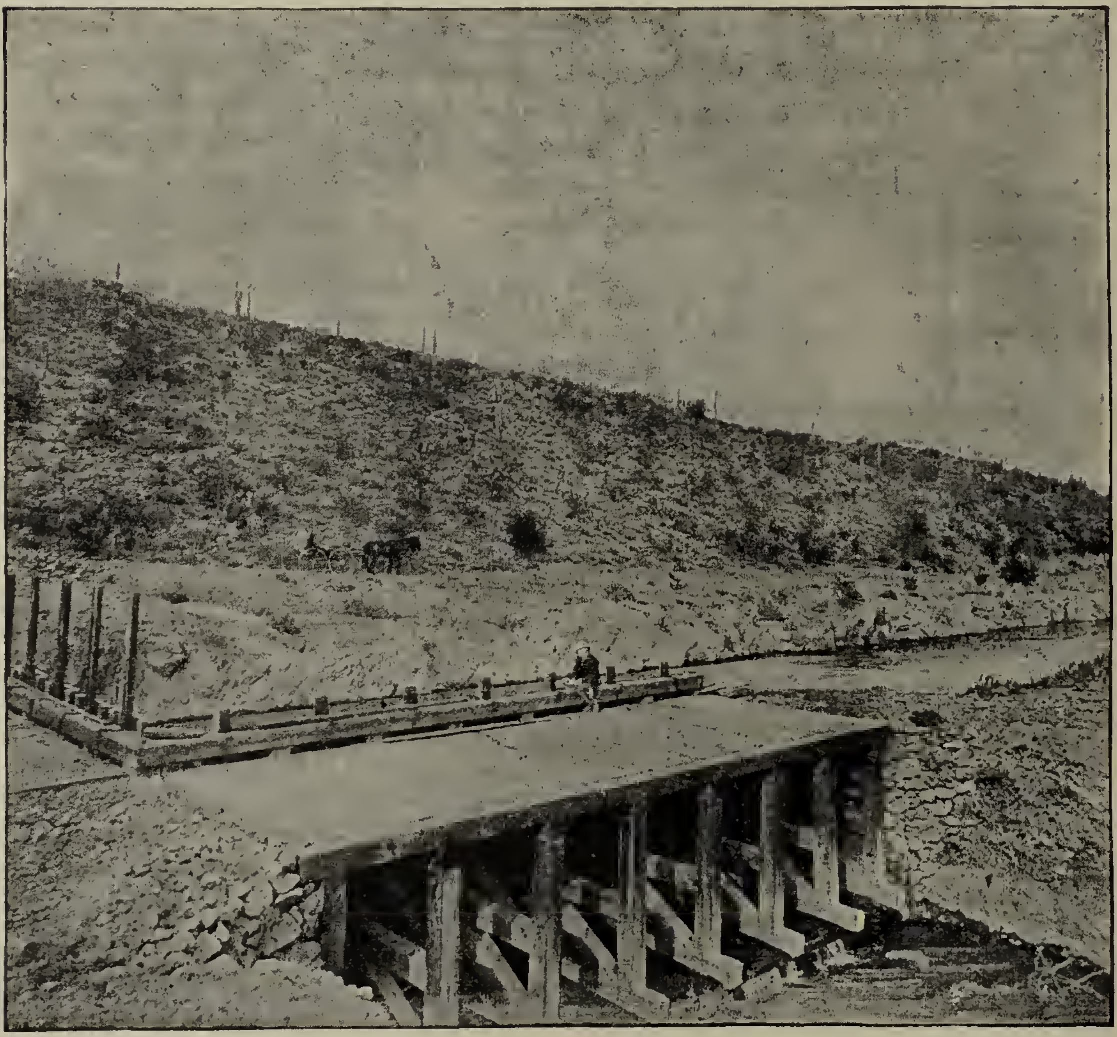
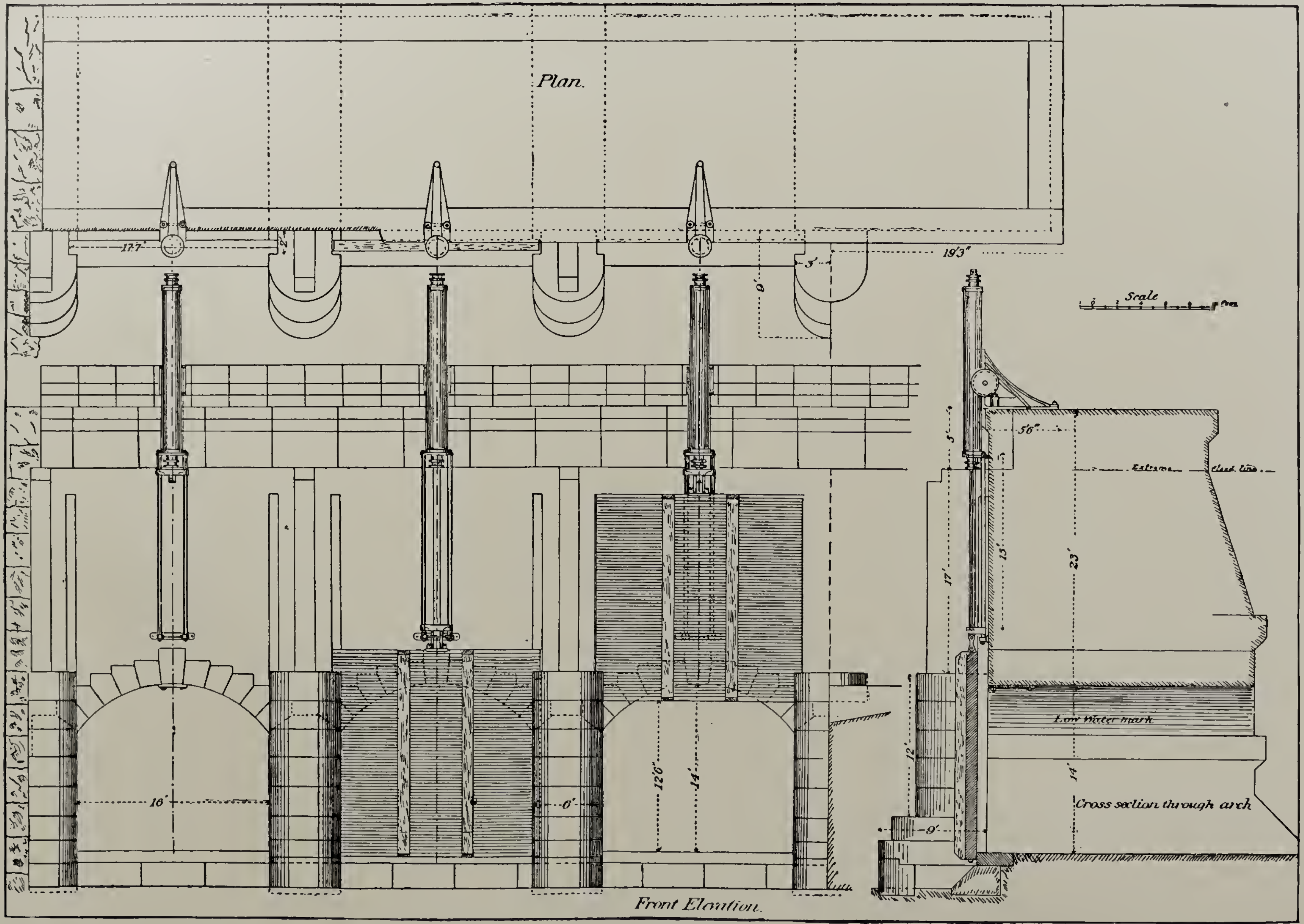


FIG. 100.—Arizona canal. View of escape.



FOLSOM CANAL. PLAN, CROSS SECTION, AND ELEVATION OF REGULATOR.

of 80 feet and a height of 12 feet, with a strong apron of wood at the upper end extending at an angle of 45 degrees downward for 12 feet into the bed of the canal.

At the head of the Pecos canal is an escape placed between the upper and lower set of regulating gates, and described on page 237. There is nothing of particular interest elsewhere on the line of this canal other than an escape at the bifurcation of the East and West branches. In this bifurcation is an escape closed by five gates, and from this the water is discharged directly back into the Pecos river. Below the escape in either branch is a set of regulating gates, so that the water can be turned in any quantity desired into either branch or wasted through the escape.

Ample provision is made on the line of the Bear river canal for the discharge of the surplus water by means of escapes. On the main West Side canal the first and principal escape is placed 1,200 feet below the regulators and 600 feet, farther down is another escape, both discharging back into the river over the steep rock walls of the canyon. Each of these escapes has 12 feet of clear opening. They consist of 3 gates each, constructed of wood, sliding between iron posts, and are raised by means of a screw gearing. Below the lower escape is a set of five regulating gates, each 4 feet in width, set across the channel of the canal, and constructed in a manner similar to that of the escape gates. The water from the escapes is discharged into about 60 feet in length of wooden fluming before being permitted to fall on the rocks of the canyon wall. The channel is floored with wood, and wooden timbers are set into the banks and filled in behind with broken rock. The iron posts between which the gates slide are firmly held in a wooden framing above and below, and the gates are raised by means of screws attached to their upper ends, which are operated by means of endless screws attached to hand wheels set in the framing above.

On the line of the Turlock canal ample provision is made for the escape of surplus water. Five hundred and sixty feet below the entrance to the canal and immediately above and opposite to the head regulator is an escape, the discharge cut of which is excavated through rock and empties directly into the river. This escape consists of six gates each 13 feet in the clear and 12 feet in height. They are of ample capacity to discharge all of the water which may enter the canal above this point. Escapes are set in the flumes crossing the various creeks and likewise in the diverting dam built across Dry creek and Delaney gulch. The escape way in the Dry creek dam consists of two parts, one 51 feet in length and the other 30 feet in length, thus affording ample discharge capacity not only for the surplus waters carried by the canal, but also for the floods which may come down the creek. The most interesting escape on this canal is in the flume crossing Peasley creek. This flume is 20 feet in width and 7 feet deep, and is carried on a trestle 60 feet in height above the bed of the creek. In the bottom of the flume is built the escape; this latter is of sufficient capacity to discharge the full volume of water flowing in the canal, and is built by laying an iron I-beam across the floor of the flume. This I-beam revolves on an axis turned by means of a hand crank, and attached to it is a portion of the floor of the flume, which is in fact a revolving gate, thus opening the bottom of the flume for its entire width and permitting the water to drop through. Below this gate is a receiving box, which discharges up and down stream into two inclined wooden flumes entering into Peasley creek, the bed of which is of hardpan. The discharge gate is operated by means of a rack and pinion attached to the end of a hand crank.

In the Idaho canal each creek crossing serves as an escape channel for the canal, while at the end of the canyon below the head of the canal is the main escape, capable of discharging the entire capacity of the canal back into the river over the lava bluffs which border it at this place. This main head escape is constructed, as are the other escapes on the line of this work, of cement pipes let through the canal bank inclosed on the water or inside face by a wooden gate operated from above by means of a rack and pinion and handwheel. The general mode of construction of these works is illustrated in Fig. 101. The concrete pipes used as the escape way are 48 inches in diameter, and are built near the site of the escape in which they are to be placed.

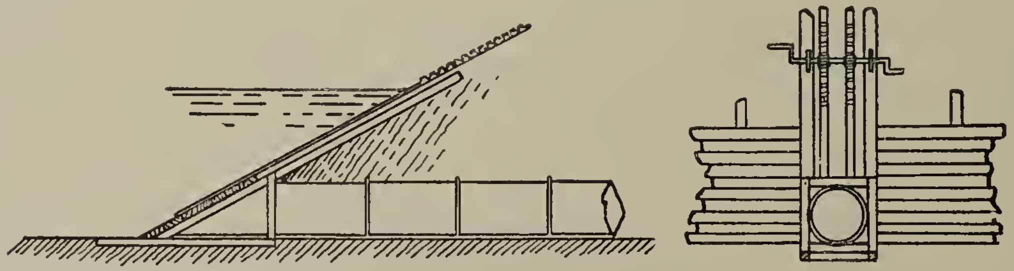


FIG. 101.—Idaho canal. Elevation and cross section of escape.

As mentioned elsewhere, sand or escape gates are constructed in the bank of the Folsom canal immediately in front and above the head of the East Side canal. In addition to these, other sand and escape gates are placed, one just below the regulators and others at points lower down. In the first 1,700 feet of the canal are seven separate gates placed at different points, though one set consists of two gates, the others being single. These gates are all similar in construction, 5 feet in width by 10 feet high, and are framed in substantial masonry built into the side wall of the canal. Across the bed of the canal opposite and below each of these is a subchannel or catch basin one foot in depth, the object of which is to collect silt carried in suspension and scour it out when the gates are open. The chief reason for such abundant provision for the removal of silt in this work is because the water is used just below these gates in turbine wheels to produce power, and it is desirable for this purpose to have the waters as clear as possible.

The main escape just above the head regulator consists of six gates, the sills of which are placed 6 feet below the grade of the canal (Fig. 102). The masonry wall bordering the canal at this point is about 8 feet in width on top and 11 feet in height. The outer slope of this wall has a batter of 1 in 12. Each of the four gates closing these escape openings is 5 feet in width by 6 in height in the clear, and is constructed of wood 6 inches in thickness. These wooden gates are raised and lowered by means of a handwheel and endless screw working on ratchets set in the back of the gate.

FALLS AND RAPIDS.

If a canal can be so located and aligned that it shall skirt the slopes of the country on a grade contour it is possible to give it the most desirable grade throughout its length; but if, on the other hand, it has to run down the slope of the country, or has to be located in such position that the fall of the country through which it runs is greater than the slope of the canal, it becomes necessary to compensate for this difference. This is best done by concentrating it in a few points by the introduction of falls or rapids. These are placed at convenient distances, so that the height of each shall not be too great, and at points where the level of the canal has reached the maximum height allowable above the surface.

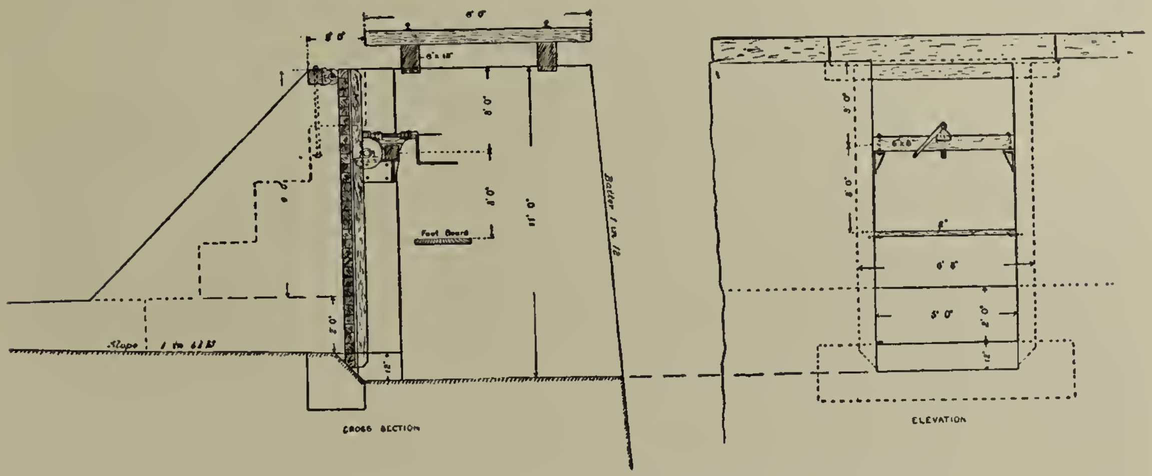


FIG. 192.—Folsom canal. Cross section and elevation of sand-gates.

In the earlier American canals it was customary to give them the same slope as the country through which they ran, and they were permitted to erode their bed and banks as they pleased. By putting most of the steep grade in straight parts of the line and by easing up the grade on curves little damage was done beyond the deepening of the canal bed. This, however, caused the canal water to be at some distance below the surface of the land and rendered it difficult of diversion in addition to the other disadvantages attending such loose practice. One of the most notable instances of this class of construction is illustrated by the Del Norte canal, in Colorado, which has in one place in its upper reaches a fall of 528 feet per mile, and in another place a fall of

20 feet per mile, while in one place, where it runs over hardpan and gravel, the fall is 35 feet per mile. Here, however, the line is straight, and as a consequence little damage has been done by the erosion of the current. In Pl. CXII a view of this canal is shown, which gives an idea of the velocity of the water. It will be seen, however, that though this work has been in operation for about eight years comparatively little erosion is visible.

The effect of a fall is to increase the velocity and diminish the depth of water for some distance above it. This increase of velocity produces a dangerous scouring on the beds and banks of the canal, and in properly constructed falls it is guarded against by heading the water up at the crest of the falls by means of flashboards or by narrowing the width of the canal at this point. The height to which it is necessary to raise the crest of the fall is found by the following formula given by Col. Dyas, of the Indian engineers:

$$H=\left(\frac{900A^2d}{l^2s}\right)^{\frac{1}{3}}-125.8122\frac{d}{s}$$

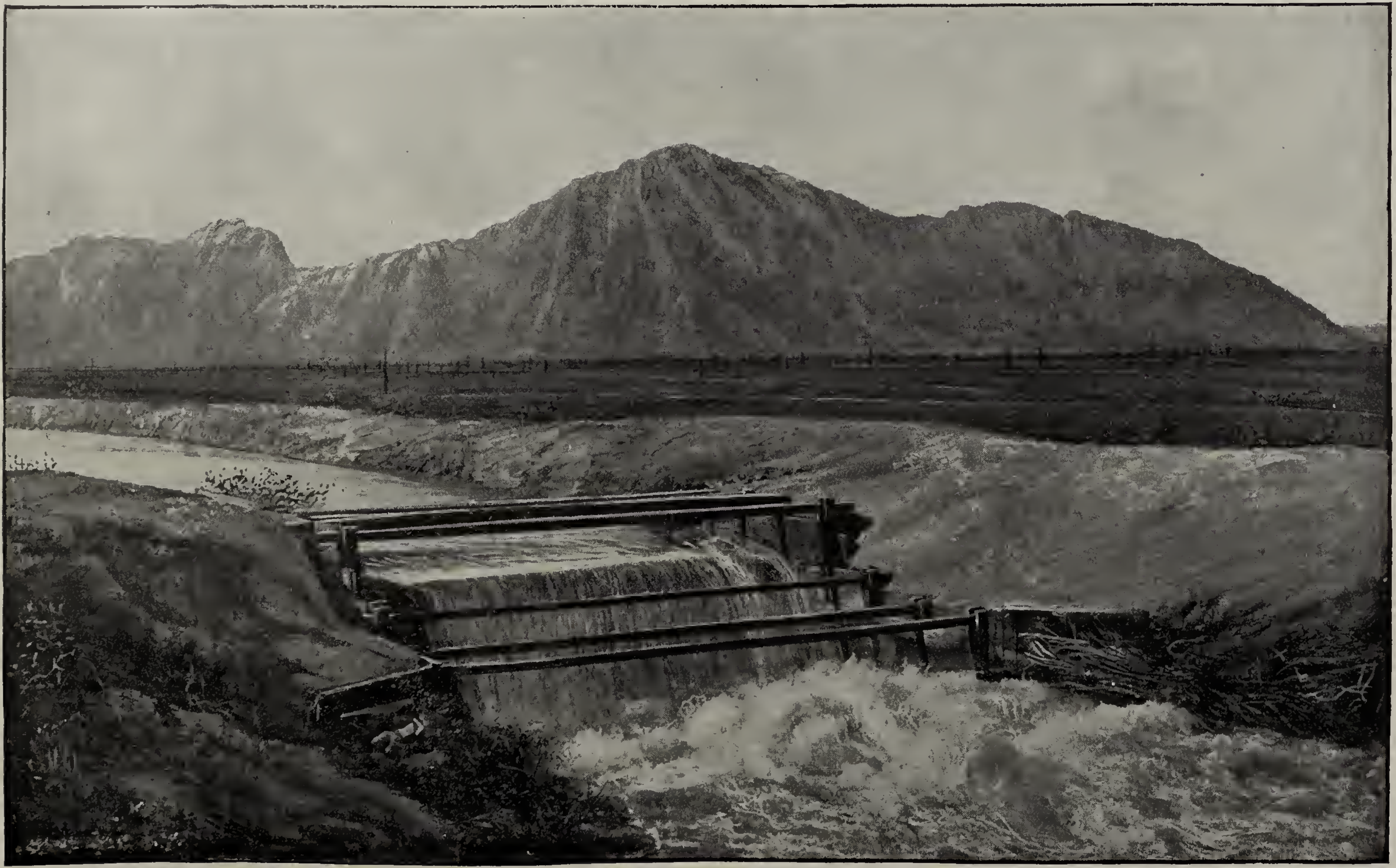
in which H is the height of the water above the crest of the fall, A is the sectional area of the open channel, d the hydraulic mean radius of the same, l is the length of the crest of the fall, and s the length of slope to a fall of one in the same.

If the channel is to be narrowed above the fall in order to diminish the velocity and the consequent erosive action, the amount of narrowing may be calculated by the common weir formula. Another method of retarding the velocity of the water or of preventing its velocity immediately above the falls from becoming so great as to erode the banks is by the introduction of gratings. These gratings are not employed on American canals, but they are used with excellent results on some canals in India. They consist of a number of inclined wooden bars placed just above the crest of the fall, and the method of spacing them is such that the velocity of no one part of the stream shall be either increased or retarded by the proximity of the fall.

The practice of constructing water cushions at the foot of falls is coming somewhat into vogue in this country, though they are not nearly as extensively used as they might be. They are very effective in neutralizing the scouring effect, especially of high falls, and their introduction will not add to the cost of the structure, but may cheapen it as it renders possible the introduction of less expensive aprons and abutments below the fall. In India, water cushions are extensively used, not only on canal lines, but below diversion weirs. In the latter case their construction is affected by the building of a subsidiary weir of smaller dimensions some distance below the main weir, thus backing the water up against the toe of the upper weir and giving a cushion on which the waters may fall.[1] This device has been introduced below the diversion

---

[1] H. M. Wilson, Irrigation in India, Twelfth Annual Report U. S. Geological Survey, 1891, pt. II, 493, 511, 535.



ARIZONA CANAL. VIEW OF FALL.

weir of the great Turlock canal, though this is the only instance of the kind to be found in this country. Water cushions have been employed on canals for sometime, on a few of the falls of the Fresno canals, and have been introduced on the line of the Turlock.

In the West the contrivances employed for overcoming grade by means of falls are variously known as falls, drops, or checks. I prefer the former, though the word "checks" well expresses the character of some of these works. On the Calloway canal the form of fall used is identical with the style of construction employed in head-gates and other regulating gates. By increasing or diminishing the number of flash-boards inserted in these checks the height of the fall can be increased or diminished as desired. One of these falls, which, as will be seen, acts at the same time as a check to divert the water into distributary channels, is illustrated in Fig. 103.

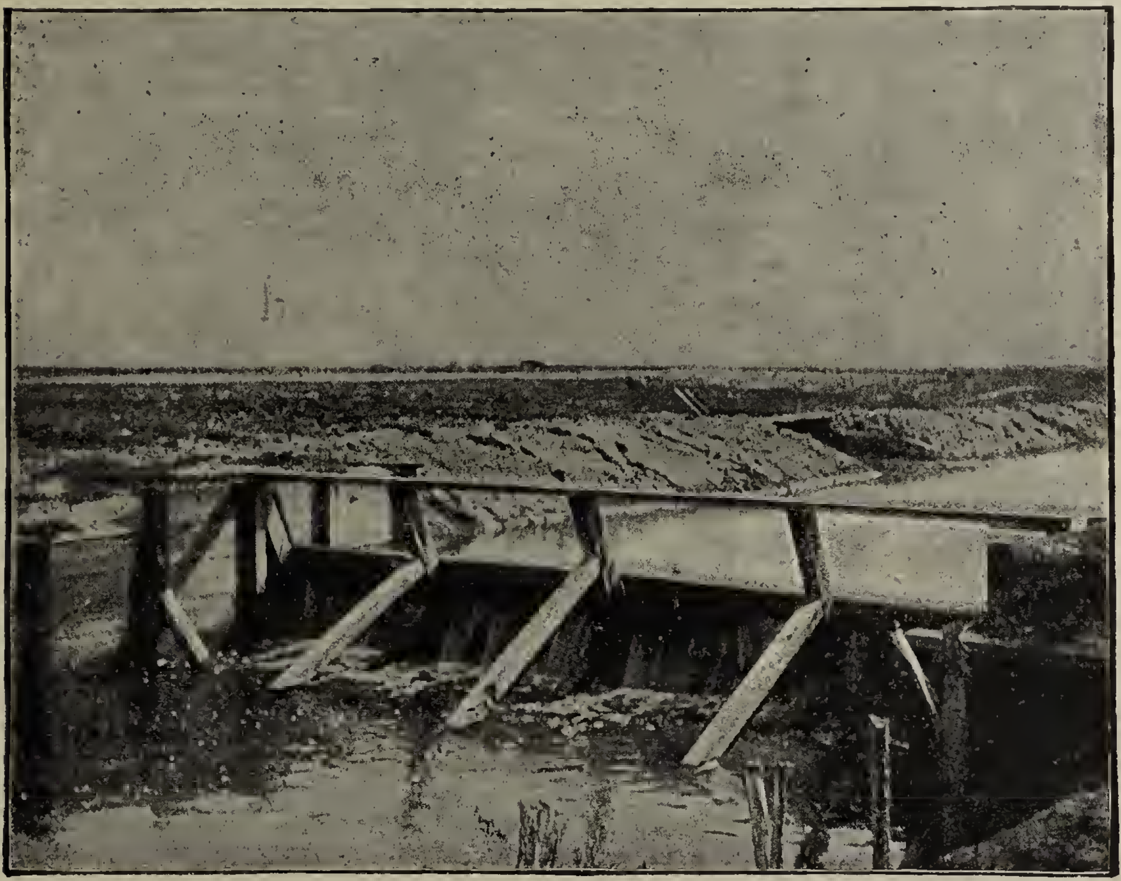


FIG. 103.—Calloway canal. View of fall.

On the line of the Arizona canal a somewhat similar form of fall is used. On the line of the crosscut which runs down the slope and is about 4 miles long, the total fall is 128 feet, which is concentrated in twenty-four falls of about 5 feet each. (Pl. CXXXIV.) The width of these—in other words, the length of the crest of the fall—varies between 18 and 21 feet. They consist practically of wooden fluming (Fig. 104), the flooring of which is 12 feet in length above and below the fall. This rests on rows of sheet piling, while sheet piling is driven under the upper ends of the floor or apron. The banks of the canal at this point are protected by wooden wings which terminate above and below the flooring by turning back into the canal banks at an angle of about 45°.

A different style from those above described is used largely on the Fresno canals. These falls range in height from 2 to 8 feet, and, as shown in Fig. 105, consists of a wooden fluming made by a flooring resting on mudsills, with sheet piling at the end, the sides being wooden wings fastened to anchor piles in the canal banks. Above the check the wings slope back at an angle of 45° into the canal banks, while below it, at the end of the apron, they are set straight back into the canal banks at right angles. The apron just above the check slopes downward at an angle of 45°, and is filled in on top with dirt to the level of the grade of the canal below the check, and the flooring is lowered 1½ feet below the grade of the canal, thus forming a water cushion on which the scouring action of the water is neutralized as it falls. There is no piling under the floor of this fall, simply 12-inch upright scantling being let into the ground for a depth of 1½ feet. In some cases instead of a water cushion there is a box placed at the foot of the fall, formed by simply boarding over the submerged portion of the floor to a level with the canal bed and filling in with dirt. In this manner the water falls upon a dirt-filled box and its force is thus broken.

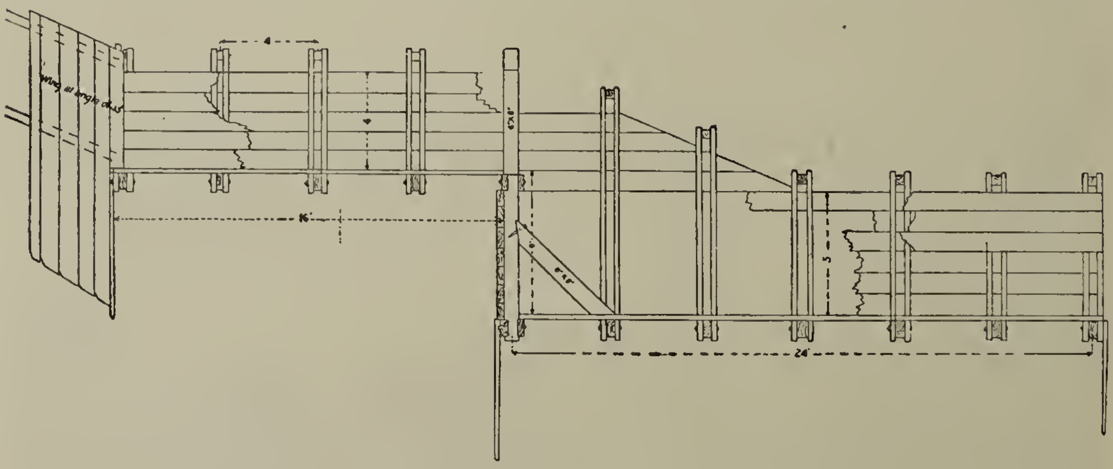


FIG. 104.—Arizona canal cross-cut. Cross sections of fall.

On the Bear river canal are a large number of falls, several of which are quite high. This is especially so on the Corinne branch, which runs down the slope of the country. On this are 16 falls varying from 4 to 12 feet in height; one of which is illustrated on Fig. 106. From this it will be seen that the flooring, like that of those just described, is of wood resting on piles or mudsills, and the banks are protected by wooden wings turned back into them at either end. In the 10-foot fall illustrated, the flooring immediately under the drop is especially heavy and the foundation on which it rests is of substantial anchor piles. Above and below the apron it slopes down into the bed of the canal to prevent percolation and undercutting.

On the line of the Turlock canal are many falls varying from 4 to 11 feet in height. Immediately above these the canal is contracted from its ordinary bed width of 70 feet to a clear width of 40 feet through the drop. This is done to reduce the velocity and thus prevent the scour above the fall. These falls (Fig. 107) are constructed of wood much as are those which have just been described. Five timbers, 12 by 12 inches are set upright on the upstream face and let down 4 feet below the level. These are gained into mudsills and dowled and planked on their faces as are the mudsills. They are so arranged as to produce for a 5 foot fall a 4-foot water cushion in which the water drops. Below the

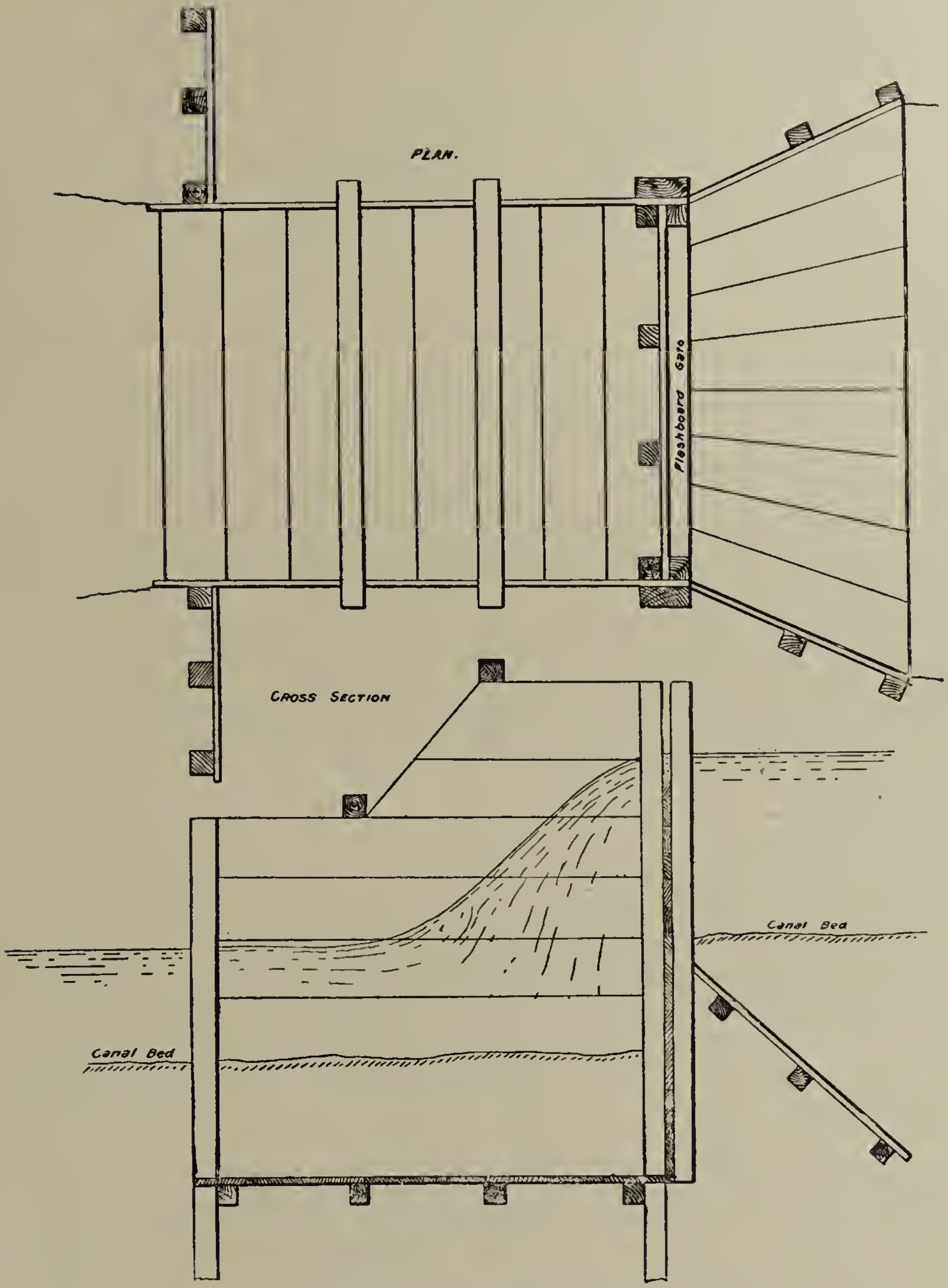


FIG. 105.—Fresno canal. Plan and cross sections of falls.

water cushion a wooden apron is built out for 16 feet terminating in a row of sheet piling and above the check in the fall a similar apron is carried for 16 feet. The 5-foot falls have water cushions 4 feet in depth; the 11-foot falls have water cushions 6 feet in depth. These falls are divided into 4 bays of 10 feet each by means of three vertical rows of planking placed in the fall. These keep the course of the current straight beyond the water cushion and fall and prevent back currents

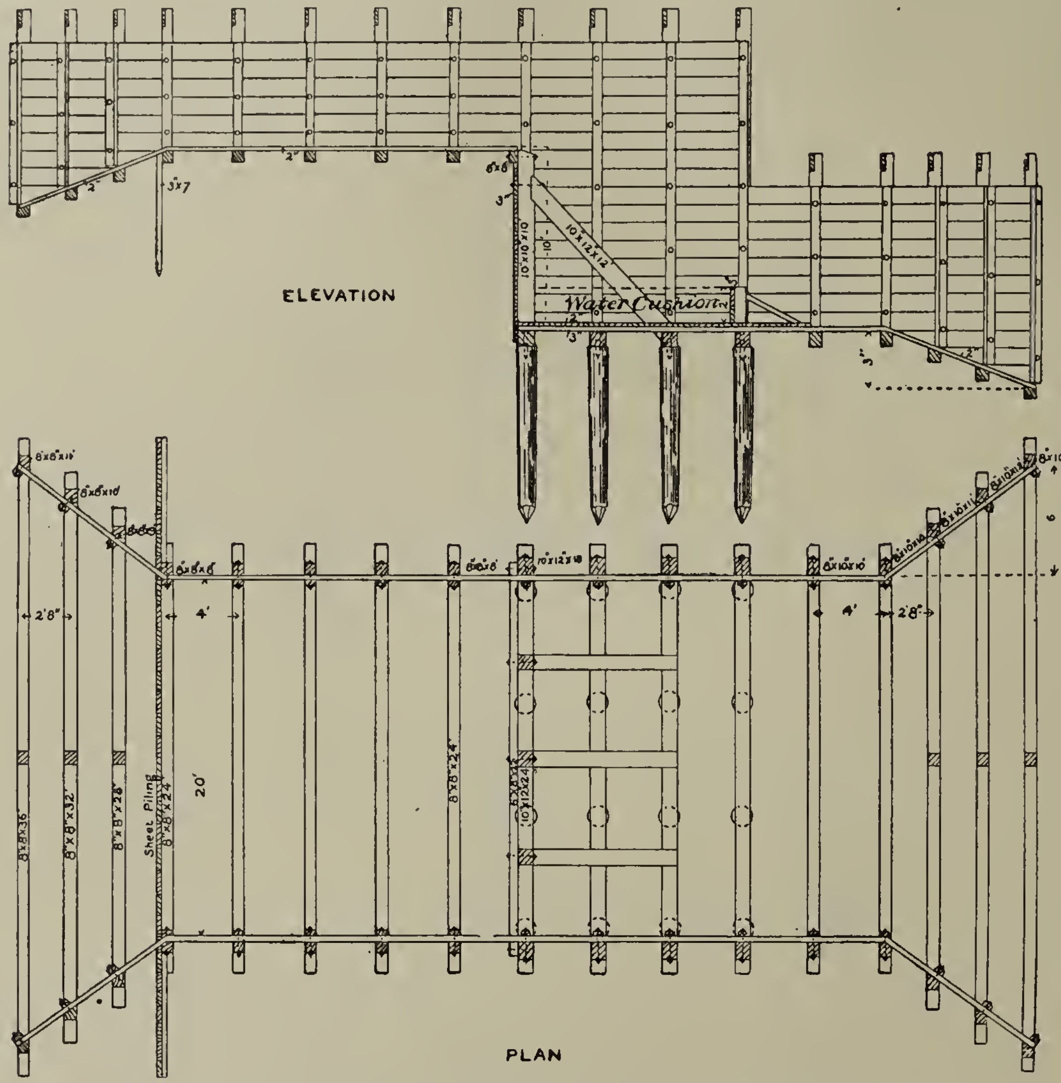


FIG. 106.—Bear river canal. Plan and cross section of fall on Corinne branch.

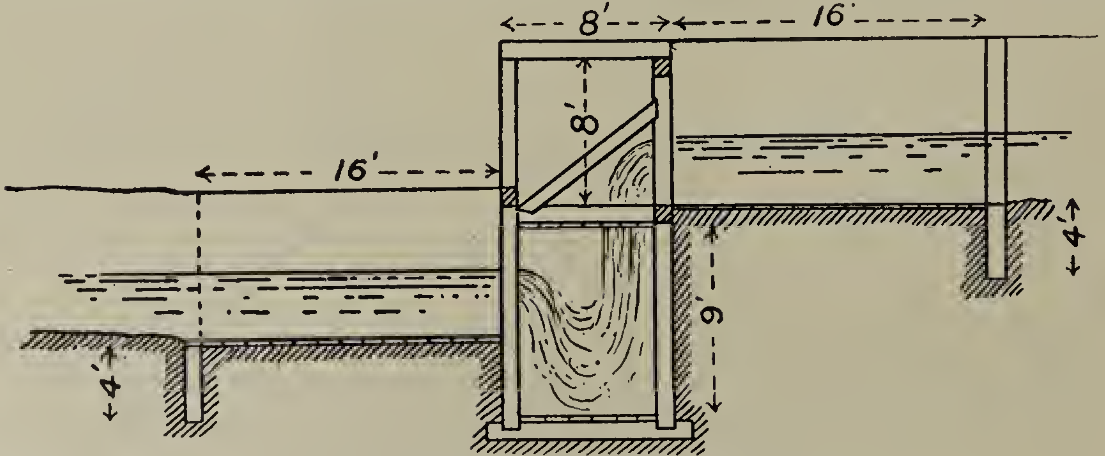


FIG. 107.—Turlock canal. Cross section of fall.

and scours and aid in the widening of the channels by means of wings from 40 feet to the original 70 feet.

A remarkable fall is one introduced on the lateral flume on the Uncompahgre ditch in Colorado (Fig. 108). This consists of two vertical drops, each 7 feet in height, and placed immediately one below the other; the length of fluming from one drop to the other being 15½ feet. The floor at the bottom of these falls slopes upward away from the check in such manner as to give a partial water cushion 1½ feet in depth below the fall.

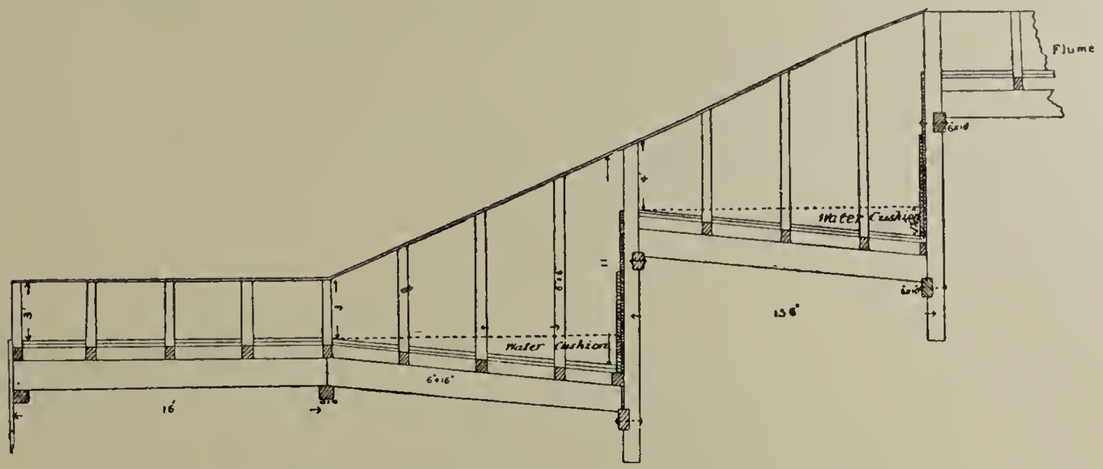
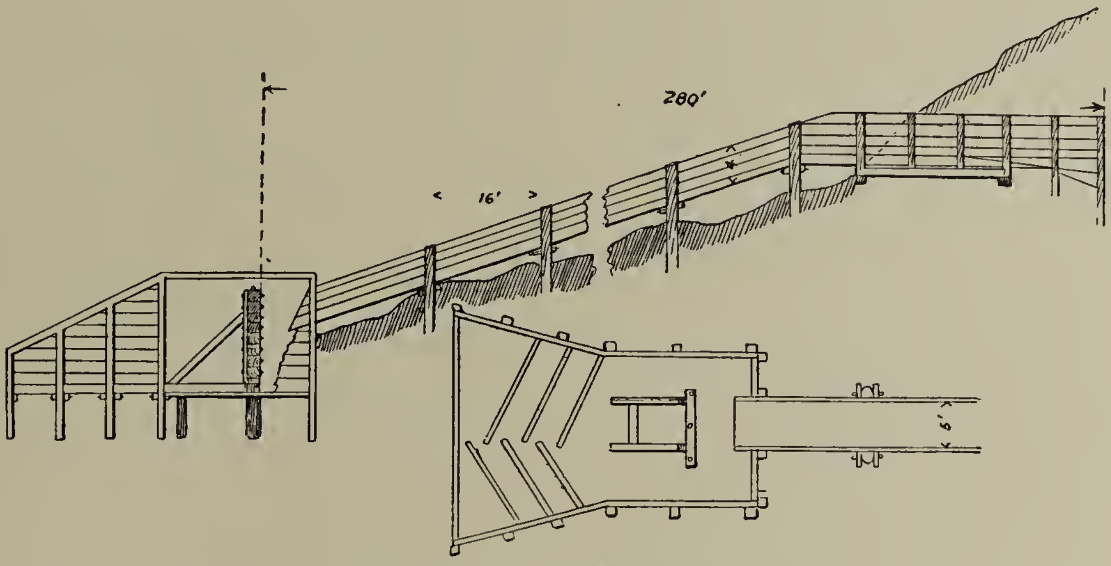


Fig. 108.—Uncompahgre canal. Cross section of fall.

In some cases rapids have been introduced to neutralize the grade in place of the falls. A notable instance of this is the "Big Drop" on the Grand river canal in Colorado (Fig. 109). The canal above the fall, which is 30 feet wide and 4 feet deep, is narrowed down into a sluice or inclined flume 5 by 4 feet, which descends with a grade of 35 feet in 125. The water is discharged from this flume against a solid bulkhead of timbers, which throws it back into a wooden penstock, whence it escapes over a riffled floor 16 feet in length, beyond which is an addi-



PLAN OF PENSTOCK

Fig. 109.—Grand river canal. Plan and elevation of Big Drop.

tional length of plain floor or fluming 16 feet long, whence it runs into the open canal again.

On the line of the Boise canal in Idaho the grade slopes of the country are neutralized by means of rapids somewhat different from those just described. One of these on the Phyllis branch of the Boise canal is illustrated on Pl. CXIX. In every case these rapids or chutes are either in wooden flumes, as represented in the illustration, or in rock excavation or masonry. The smaller rapids, of which the illustration represents one, have slopes generally of from 1 to 5 feet in 100. On the line of the main eastern branch are several very heavy rapids similar to those just described. These range in height from 12 to 49 feet.

DRAINAGE WORKS, FLUMES, SIPHONS, ETC.

A majority of American canals are diverted high up on the streams from which they derive their supply, so that they may have sufficient grade to command the largest possible area of land. As a result of this location they necessarily encounter much sidehill drainage as they pass down the slope or are aligned around the sides of the foothills. Many of these canals, even after they reach the open valleys or plains, have to encounter in their course large streams which they must pass, while railways and wagon roads present to the minor branches of these canals obstacles which must be passed by means of special devices. Much may be done by diverting the water courses near the head of the canal; minor drainage lines carrying but small volumes of water may be admitted directly by simple inlets into the canal or may be crossed at grade by admitting their waters into the canal and passing them on through by means of escapes or other devices in the opposite bank. In some few cases drainage has been passed where the slope of the drainage channel was steep by the construction across its mouth of an earthen dam or embankment, thus forming practically a reservoir on the line of the canal. The effect of this is to cause the waters of the canal to spread out at such a point and to offer a large surface for the losses by absorption and evaporation. In the course of a short time, however, these depressions will ordinarily be filled by sediment and the canals can then be given their proper cross-section through the filling.

On the line of the Arizona canal are several level crossings by means of simple inlets through the upper canal bank. In a couple of instances where moderate-sized drainage channels are crossed these are admitted to the canal by simply constructing the bank on the lower side of a height a little greater than that of the crest of the remainder of the canal bank, in order to prevent sudden floods from topping it. The result is the waters spread out on the upper side of the canal and form a swamp or small reservoir, thus increasing the evaporating and absorbing surface exposed. In no case is an inlet dam constructed on this canal, nor are there in any case escape gates introduced in the opposite bank to permit the discharge of flood waters; consequently the canal has to carry these, and it has its capacity correspondingly reduced by the deposits of silt and sand.

On the Highline canal in the first mile a drainage gulch is crossed by means of the construction of an embankment 18 feet in height on the lower side. No inlet dam is built nor escapeway provided. In the third mile this canal crosses Willow creek, the discharge of which is 1,000 second feet in time of flood. This crossing is effected by means of an earth embankment 30 feet in height, which is 8 feet wide an top and has slopes of 1 on 3 inside and 1 on 2 outside. This practically produces a reservoir in Willow creek and increases thereby the losses of absorption and evaporation in the canal. The embankment is 3 feet higher than the banks of the canal at either end, and above and below this embankment two escapeways are provided, one 300 feet in length, the other 200 feet in length, which discharge back into Willow creek over the rocky shale forming the surface of the country.

On the line of the Turlock canal several minor drainage channels are crossed near its head by simply permitting the waters to enter the canal, the bank on the opposite side being a little firmer, higher, and wider than elsewhere. In these cases no escape is provided in the bank, as the volume admitted is comparatively small and can escape at points lower down. In one or two cases only have inlet dams been provided. In some places where minor drainage channels enter along the upper portion of the diversion line of this canal, the excavated material has been piled up on the upper side, thus forming an inlet dam. As a consequence the canal bank is narrowed down to its proper width and there is no resultant increase in the loss by evaporation. Neglect to build inlet dams at level crossings is one of the most serious defects in the construction of American canals. They entail an additional first cost of construction and their omission is excusable while water is still abundant, but they should be provided when water becomes scarce and its loss a serious matter.

The most interesting drainage dams have been built on the line of the Turlock canal. In one place the canal emerges from a tunnel and crosses Delaney gulch by means of an earth dam thrown across its lower side. The water flows from the tunnel just above the dam and passes out through a cut just below it. This dam is of gravel and earth, 40 feet high and 180 feet long, with slopes of 1 on 2 and a top width of 2 feet. The drainage brought down by Delaney gulch is insignificant in amount and accordingly no escape is provided.

At the point where the waters of the Turlock canal are diverted from Dry creek an interesting dam has been built. This may properly be described here, as it is both a drainage and a diversion dam. It is of earth and gravel 460 feet in length and 23 feet in maximum height, with slopes of 1 on 3. A paving of stone is placed on the upper side, the total depth of which is 3 feet. This depth of rip-rapping is necessary owing to the velocity and volume of water carried down the creek. As shown in Fig. 110, the top width of this dam is 20 feet and its width at the base 100 feet. Beyond its left end is an abutment of sandstone in which a wasteway 50 feet in width and 4 feet below the crest of the dam has been cut. This wasteway discharges back into the creek over a rock ledge at a point 180 feet below the dam. Between this excavated wasteway and the end of the dam is a waste gate separated from the wasteway by means of a rock and earth abutment pier of large dimensions. This waste gate is intended to be used in times of flood and consists of ten gates, each 10 feet wide in the clear and 10 feet deep. The total width of these waste gates, including their abutments, is 51 feet and the width of their bed or flooring parallel to the stream is 20 feet. The gateways are closed by wooden gates which drop or fall outwards and are hinged to the flooring below and held above by means of chains. Upon the arrival of floods the gates are dropped by unfastening the chains and fall upon a shallow water cushion built into the flooring, which prevents their destruction by the jar caused from the fall. They are raised after the flood has subsided by means of the chains and a geared windlass. They empty into the creek below through the same channel as does the wasteway.

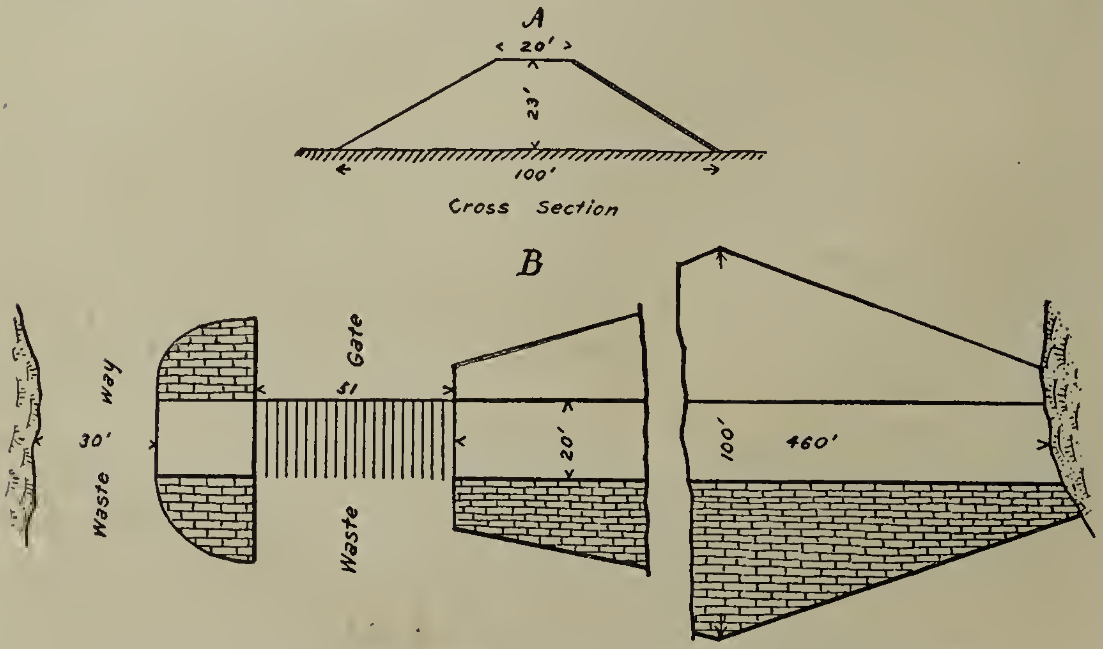
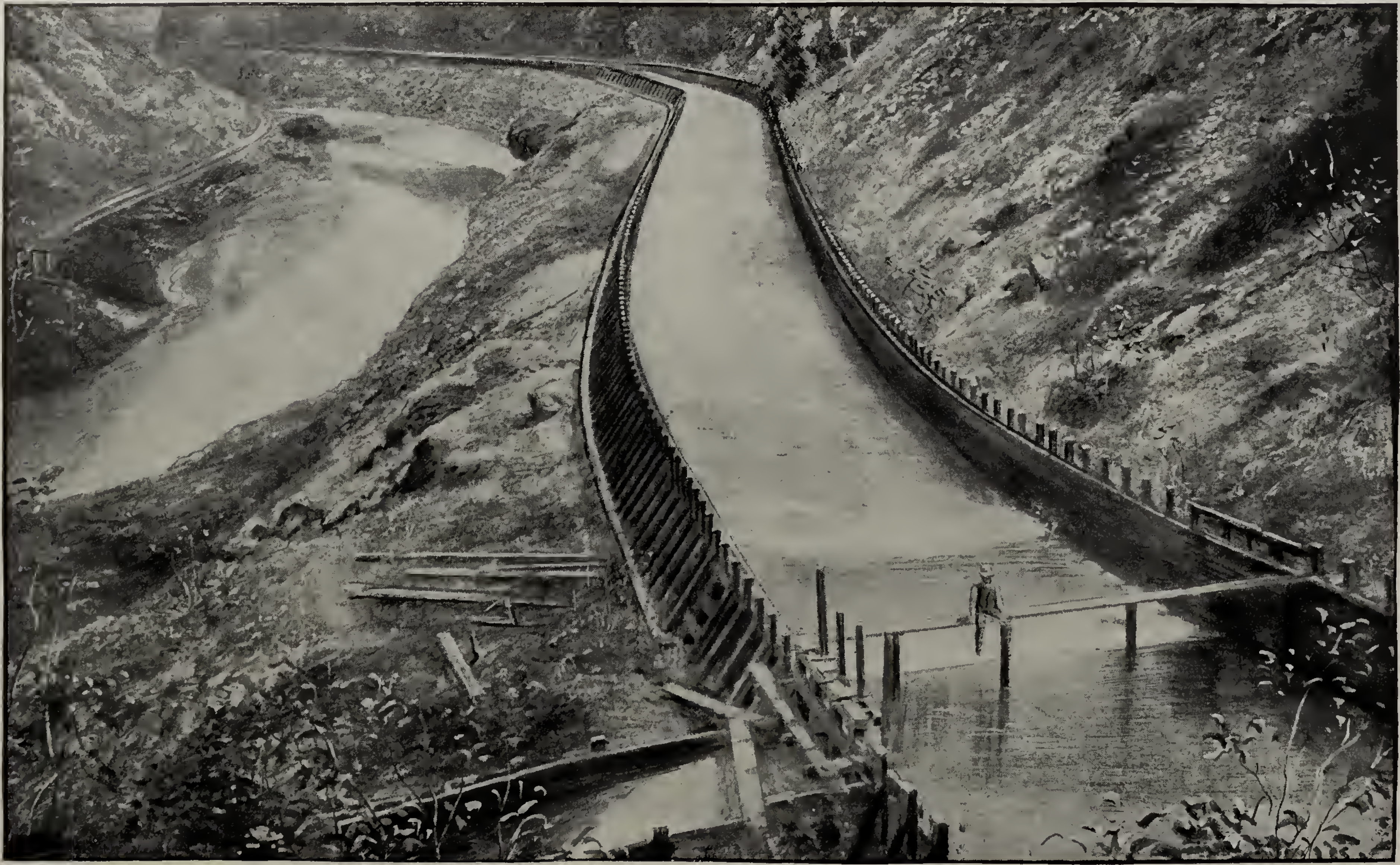


FIG. 110.—Turlock canal. Plan and cross section of Dry creek drainage dam.

When the canal is carried over the drainage channel it is generally in an aqueduct. Most American aqueducts are constructed of wood and are called flumes. There are no masonry aqueducts built in the West. A few iron aqueducts have been introduced, notably on the Bear river canal. The life of these will be so great compared with that of the average wooden flume that they must surely in the end prove cheaper and their construction be more generally adopted. The boxing of flumes is generally of three different forms. In the first the floor is built directly on the stringers and the planking floor placed at



HIGHLINE CANAL. VIEW OF BENCH FLUME.

right angles with the longitudinal axis of the flume or the flow of the water. The second style is to lay floor beams on the stringers, bracing them at intervals so as to bear the water pressure. The standards and floor beams are boxed in and bolted to the outside braces, the whole forming the foundation for the sheathing or boxing. The third form, employed more generally on large flumes, consists in framing the floor beams and stringers in cross yoke to receive the boxing. The more common lumber used in boxing is 2-inch plank, and joists are always calked with oakum.

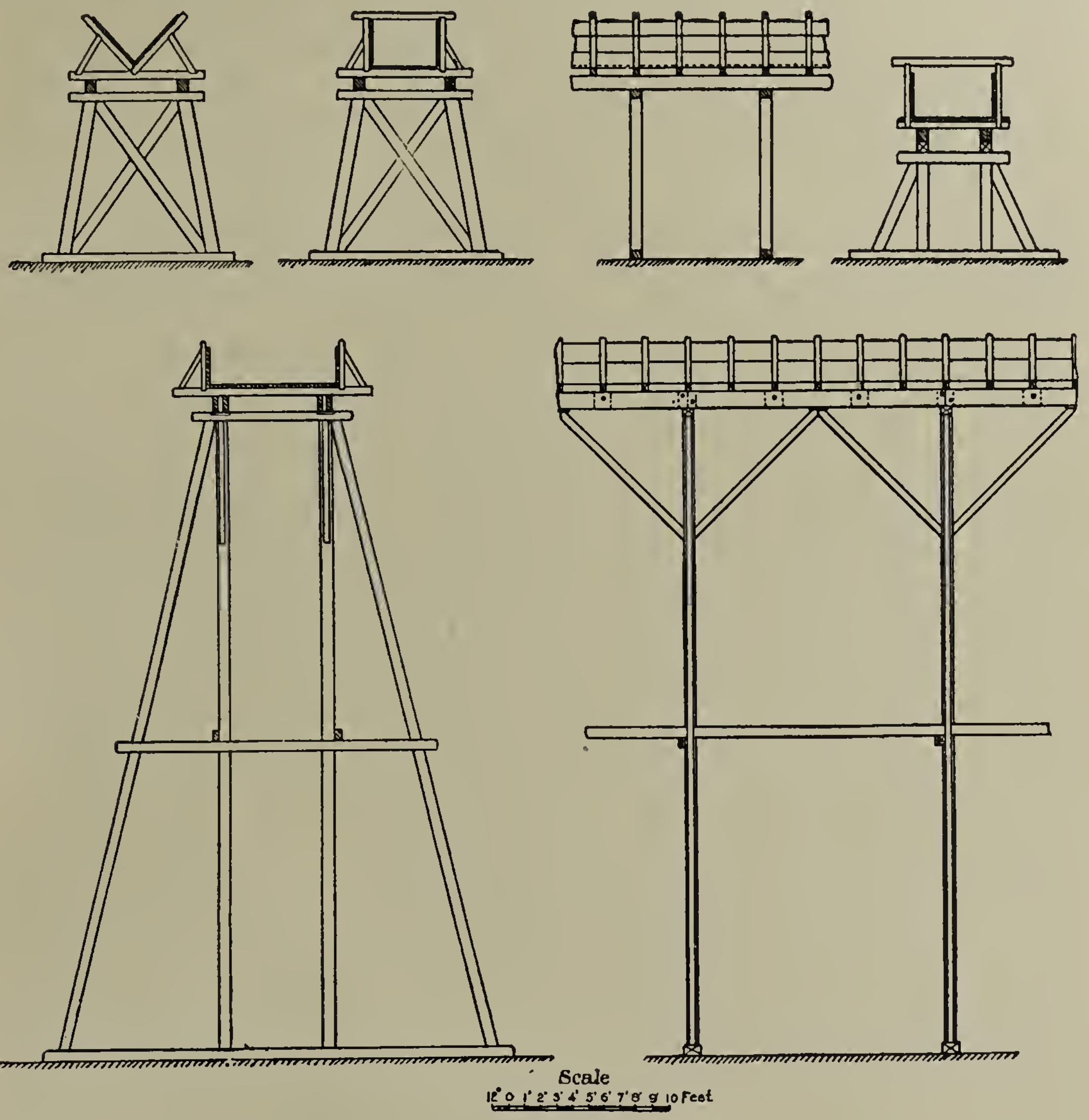


FIG. 111.—Types of flumes and trestles.

It is customary to place a waste gate in each flume, because the structure furnishes a cheap mode of introducing an escape, and because it is desirable to be able to empty the canal immediately at the upper end of a flume in case the structure should need repair. Where flumes are built on trestles the latter are usually supported on piles, though in cases where the bed of the drainage is of a sufficiently firm nature, they rest simply on mudsills (Fig. 111). The grade of these flumes is usually greater than that of the canal, thus permitting their cross section to be diminished and producing a corresponding diminution in their cost. In such cases suitable drains and wings must be provided at both ends of the flume. Where bench flumes are constructed it is customary to make the bench nearly twice as wide as the flume in order that there may be a footway for purposes of inspection and for catching material which may roll down from the upper bank and lodge on the flume. In such works the flume is usually founded on simple mudsills and crossbeams.

One of the simplest of small forms is the V flume, illustrated in Fig. 111. This may or may not rest on a trestle, according to circumstances. Such flumes are usually from 2 to 3 feet in height and from 4 to 5 feet in width on top. They are constructed simply and are more generally used in the mountain country of California, where they are of service in floating lumber from the hills to sawmills in the valleys below, the water after having done its work of transporting being employed for irrigation.

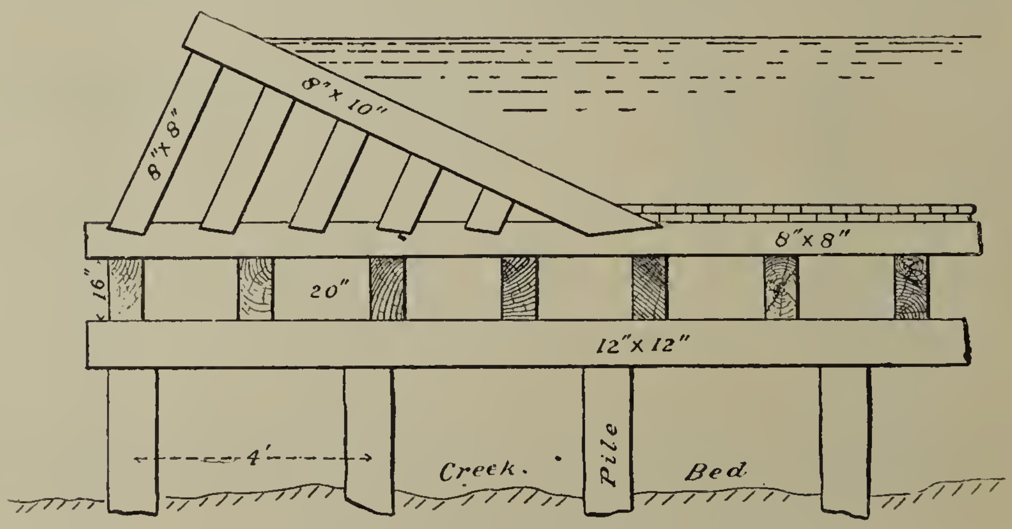
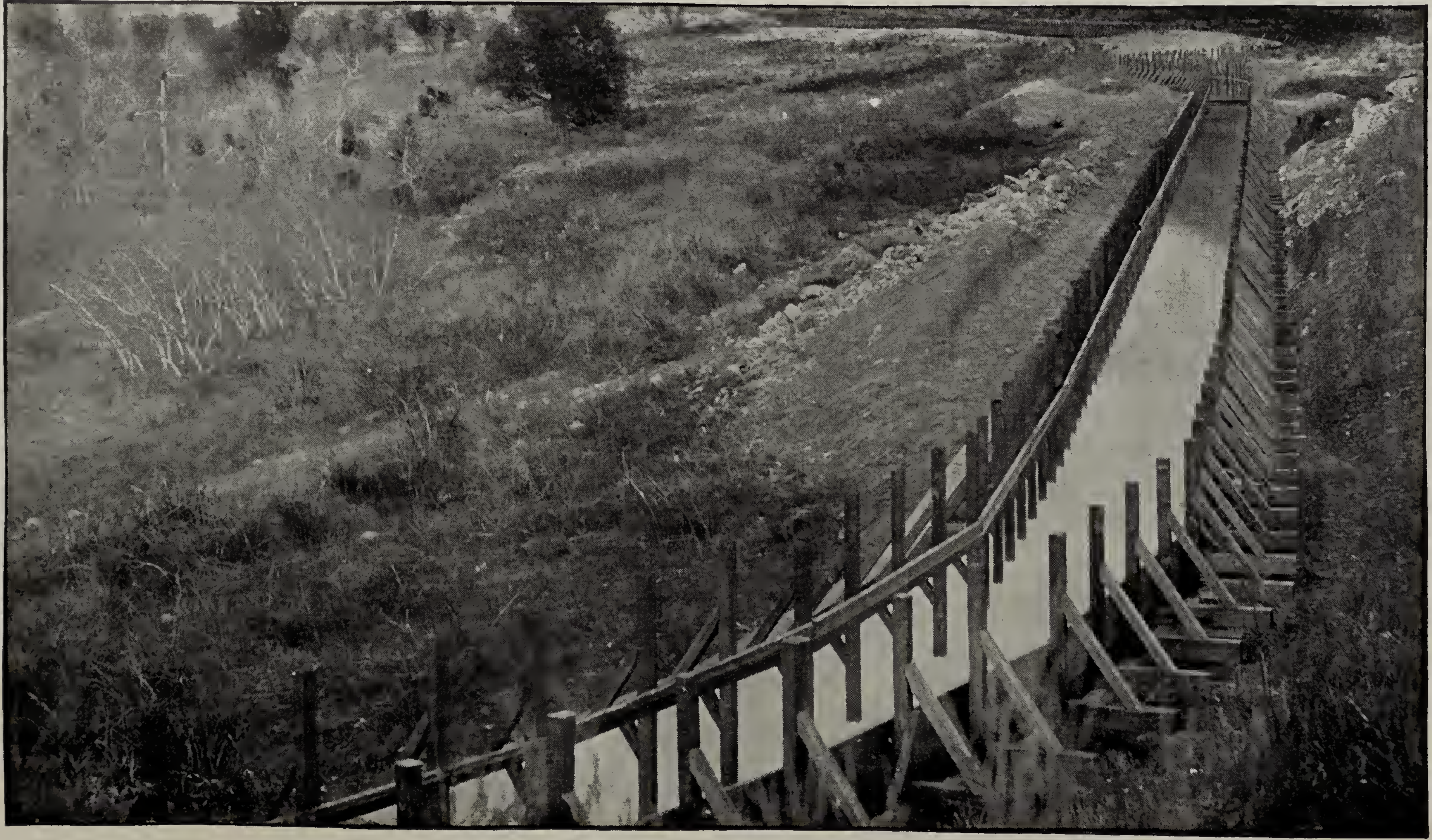


FIG. 112.—Idaho canal. Cross section of low flume.

The great bench flume on the Highline canal in Colorado is illustrated in Pl. CXXXV. This flume is 28 feet wide, 7 feet deep, and is set on a grade of from 5 to 8 feet per mile, its total length being 2,640 feet and its capacity 1,184 second-feet. The timbers supporting the flooring are sufficiently heavy and abundant to render the work substantial, while the trestles supporting it are well braced and framed. The side bracing supporting the uprights are peculiarly and expensively housed by letting them into iron castings or shoes at either end. These shoes, bolted to the woodwork of the flume, can not be said to have increased the life of the structure, as they have caught rain or leakage water and have thus added greatly to the deterioration of the wood.

An interesting form of construction for a short and low flume is employed in crossing minor drainage lines on the Idaho canal. The aqueduct across Five Mile creek is illustrated in Fig. 112. This structure is but a few feet in height and is approached by a terreplein or earth embankment, the lower or outer side of which is protected by



SAN DIEGO FLUME. VIEW ON BENCH.

masonry approaches, while masonry wings are carried along the end so as to furnish the approach to the flume. This latter structure is founded on rows of piles driven 4 feet apart across stream, and on these rest cap pieces of 12 by 12 timber surmounted by longitudinal stringers of 8 by 16 inch timbers placed 20 inches apart, on which rest 8 by 8 floor beams. The flooring is of a double thickness of 2-inch planking. The total length of this flume is 24 feet, and the width of waterway from one masonry abutment to the other is 24 feet.

One of the most interesting and oldest of the large irrigating flumes is the San Diego flume. (Pl. CXXXVI.) One of the high trestles supporting it, that across Los Coches creek, is shown in process of construction on Pl. CXXXVII. This flume is 5 feet 10 inches in width inside and 3 feet 10 inches in height from the floor to the top of the frame. Owing to the lack of water supply the interior has been boxed up but one plank in height; that is, to a depth of 16 inches. The flume, when on a hillside, rests throughout on an excavation on a bench 12 feet in width. Only where it crosses side drainage lines or creeks is it on trestles. First, planks for mudsills 12 by 2 inches are laid across the bench 4 feet apart (Fig. 113). On these rest longitudinal stringers of 4 by 6-inch timbers, above which are the floor beams also of 4 by 6, and placed 4 feet apart immediately over the mudsills. Into these are gained the upright posts 4 feet in height and of 4 by 4 scantling, braced by short stringers gained both into the posts and floor beams; the whole is then planked with 2-inch planking running longitudinally. This structure has been in constant service for five years, and as yet shows little signs of deterioration. When on trestles the sills of the flume rest on three longitudinal stringers, two of which are 4 by 12 inches and one in the center 6 by 12 inches. The trestle bents are placed 16 feet apart, and for trestles up to 20 feet in height consist of two 8 by 8 inch posts set

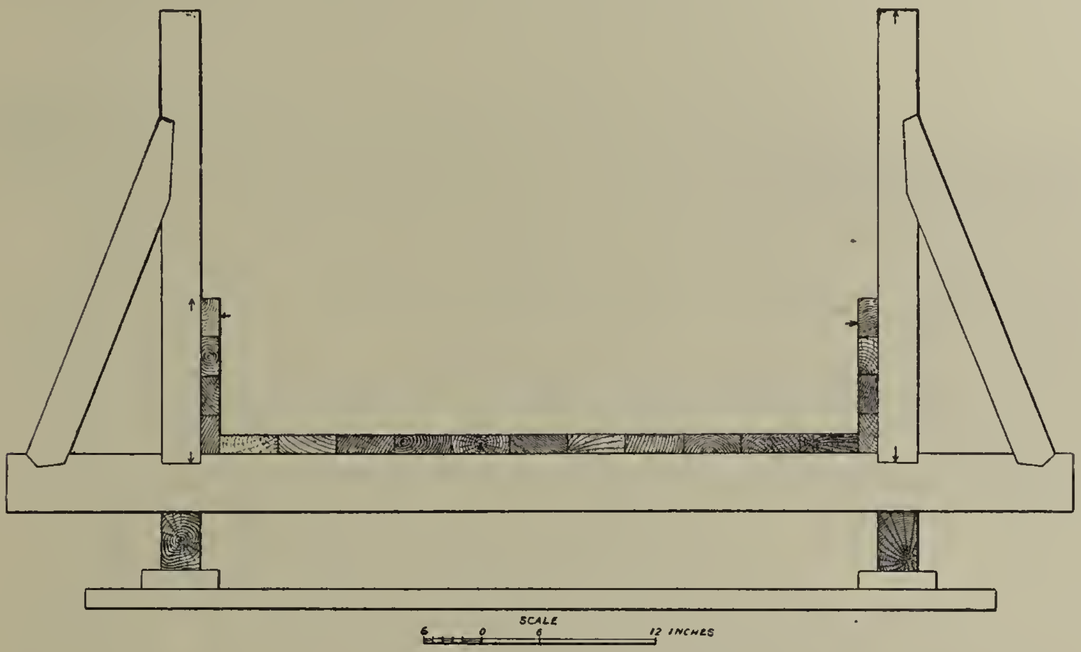


FIG. 113.—San Diego flume. Cross section.

on a batter of 1 to 6; of cap pieces 8 by 8 inches by 6 feet, and of sills 8 by 8 inches, and of diagonal sway braces 2 by 10 inches. More posts are introduced for higher trestles, and truss bridges carry the flume over the deepest gorges.

On the Pecos canal is a wooden flume and terreplein for conducting the waters of the West Side branch over the Pecos river. The bottom of this great flume is 40 feet above the river bed, it is 25 feet wide in the clear, 8 feet deep, 475 feet long, and rests on substantial trestle-work with spans 16 feet in length. Across the river bed this flume is founded on cribs drift-bolted to the solid bed rock of the river and filled with rock. The abutments of this flume at its junction with the canal, which runs on top of the earth terreplein, consist of wooden wings set back a distance of 12 feet into the earth, well braced, and supported on anchor piling and filled with earth. The planking of these wings is 2 inches in thickness. The flume rests on five sets of 12 by 12 timbers forming each bent of the trestle, and these are well cross-braced. On them rests a cap piece of 12 by 12 inches and on this are ten longitudinal stringers 16 feet in length extending from one bent of the trestle to the other. These stringers are of 6 by 12 timber and on them are nailed 2-inch floor planking placed at right angles to the current. The side-bracing of the flume consists of 6 by 8 scantling 8 feet in length; though at present these are planked for a depth of only 5 feet, giving the flume that available depth. These pieces are placed 4 feet apart between centers and are braced by short struts at each bent of the trestle. Pl. CXXXVIII gives an excellent view of this flume and shows clearly the great size of the work.

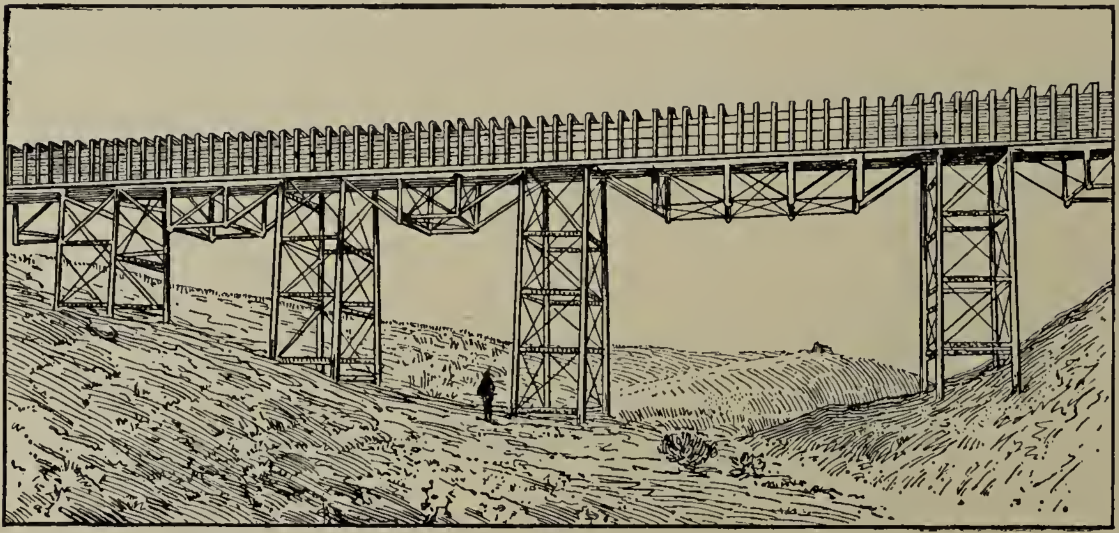
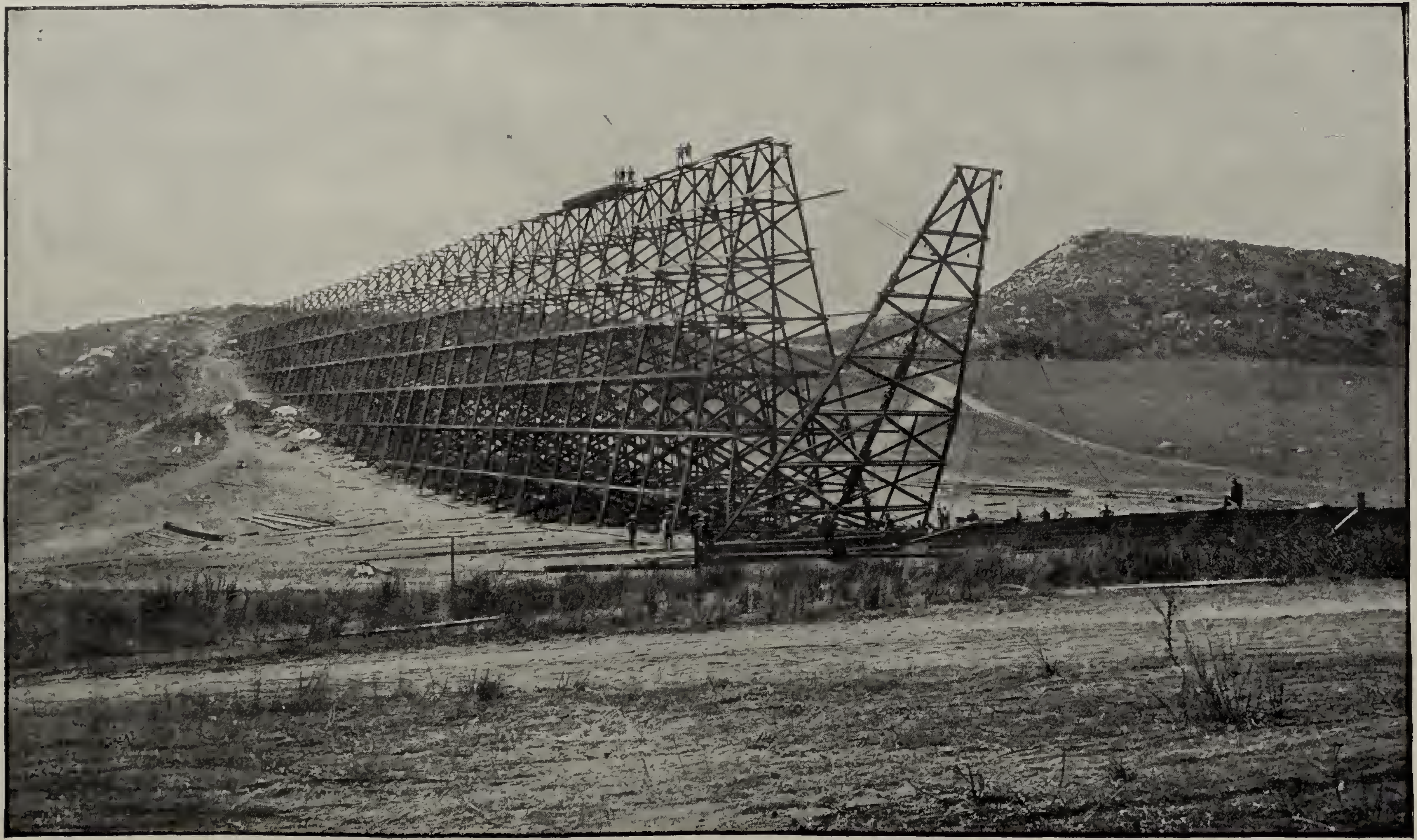


FIG. 114.—Bear river canal. View of iron flume over Malad river.

Two remarkable structures, both of which are well worthy of complete description are the great iron and combined wood and iron flumes on the line of the Bear river canal in Utah. The combined wood and iron flume carries the waters of the main West Branch canal across the Malad river. This flume (Fig. 114) is 378 feet in length and 80 feet in maxi-



SAN DIEGO FLUME. TRESTLE ACROSS LOS COCHES CREEK.

mum height, and consists of one river span 70 feet in length and of five bents, which are practically iron bridge trusses of 42 feet span. These spans are supported on iron columns, consisting of four upright posts 18 feet apart across the line of the aqueduct and 14 feet apart parallel to its line. These columns are strongly cross-braced, and are founded on boiler iron cylinders from 8 to 14 feet in length and 4 feet in diameter. Through the center of these cylinders are driven four piles, each 12 feet in length, and the cylinders are filled in with concrete, thus forming a firm masonry support. On top of each of these is placed a 12-inch capstone on which the trestles rest. All of the eyebeams forming the floors and stringers of the flume are 36 inches in height and of five-sixteenths inch iron. The flume which rests on this iron trestle is of wood, and is 20 feet wide in the clear and 7 feet in depth, resting on nine rows of wooden floor beams each 8 by 16 inches by 4 feet. The flooring of the flume consists of two thicknesses of 2-inch planking and the sides of one thickness of 3-inch planking. The approaches to the aqueduct consist of a wooden flume 500 feet in length, 20 feet wide in the clear, and carrying 7 feet depth of water. This

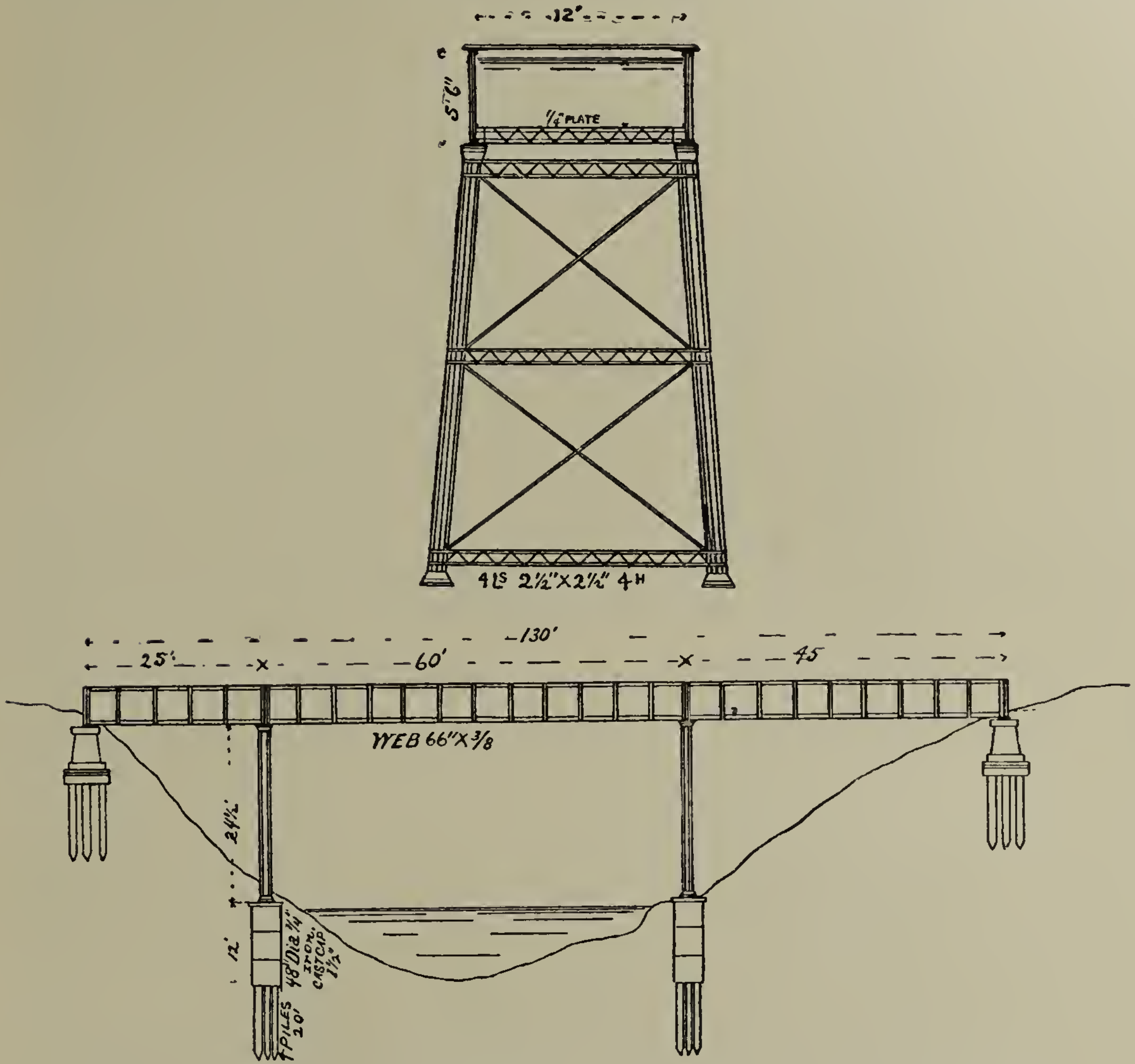


FIG. 115.—Bear river canal. Elevation and cross section of iron flume on Corinne branch.

flume is widened at either end to 30 feet, and then finally to the full width of the canal, the flume itself being practically the wings of the approaches.

On the Corinne branch of this canal is the second iron aqueduct above referred to, the floor of which is 37 feet above the bed of the river. Its total length is 130 feet, disposed in three bents, the center span being 60 feet long and the other two spans being respectively 25 and 45 feet long. This aqueduct is essentially a plate girder resting on iron columns and founded on iron cylinders and piles, as is the other aqueduct just described. The plate girders forming the sides of the aqueduct (Fig. 115) are 5½ feet in depth, its maximum width being 12 feet and the depth of water 4 feet. The sides of the girders are braced by vertical angle iron riveted to it every 5 feet apart, while the top is cross-braced by similar angle iron, the angles being 3 by 4 inches on the top bracings and 3 by 3 on the sides. The web or sides of the aqueduct consist of three-eighths inch iron, the bottom being of one-fourth inch plate. There are 50 feet of wooden flume approaches on each end of this aqueduct. It was anticipated at first that there would be difficulty in keeping this structure water-tight, owing to the expansion and contraction of the metal. This, however, was found not to be the case; for when the water is passing through it the temperature of the metal is that of the water rather than that of the air, and this is so nearly constant as to make no appreciable difference. These two iron structures have been eminently successful, and it is most likely that many more of the same kind will be constructed.

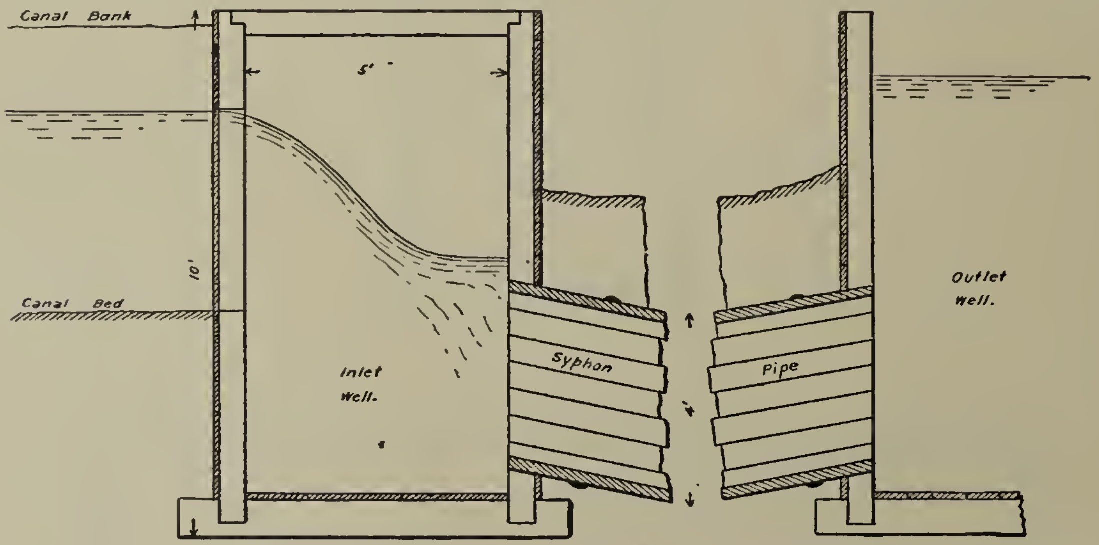
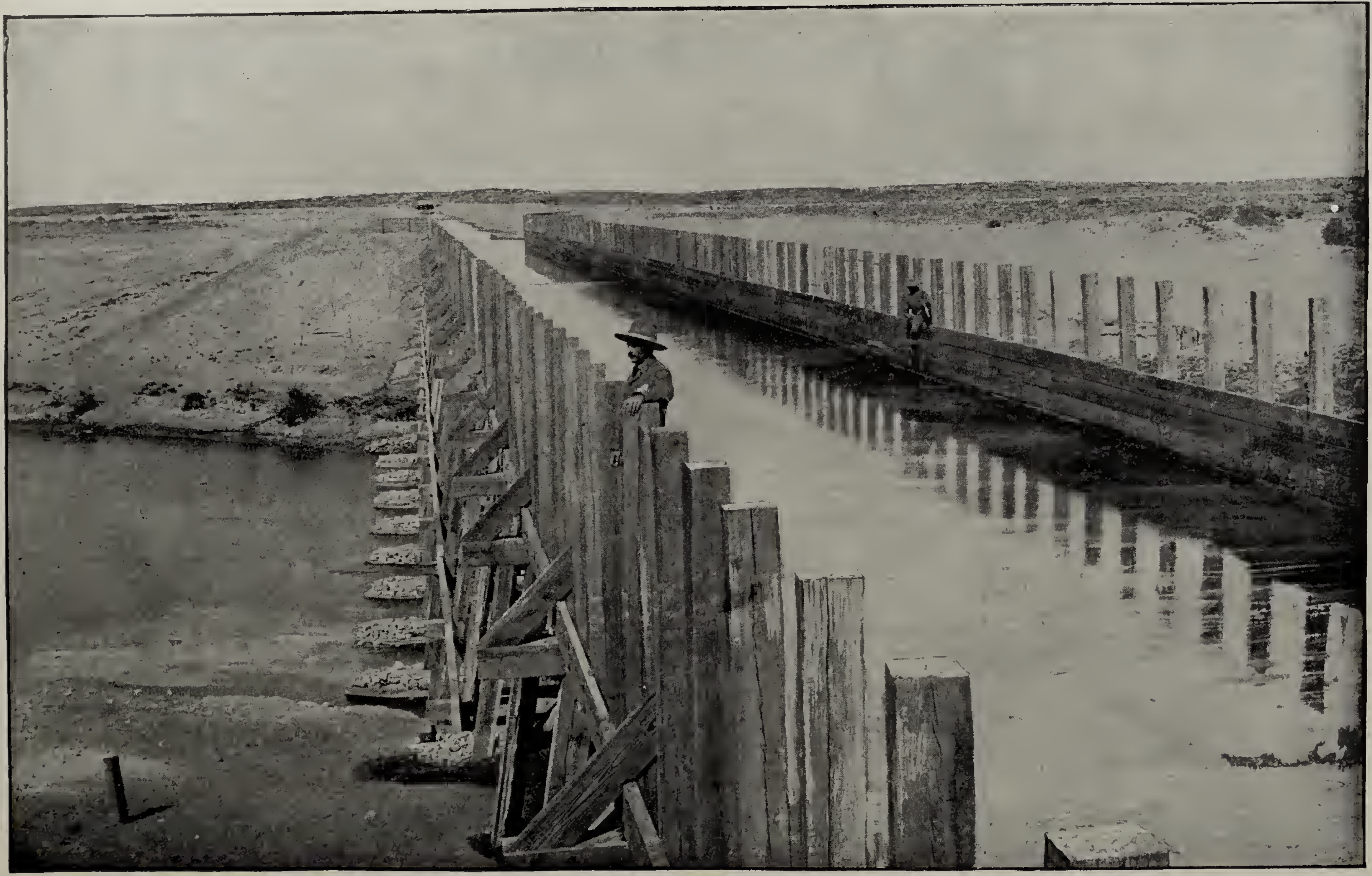


FIG. 116.—Arapaho canal. Cross section of siphon head.

One of the important forms of drainage crossing frequently used on smaller branches or distributaries, and sometimes necessary on large canals, is the culvert or inverted siphon. These are especially necessary where the canal meets the stream to be crossed at or near the same level; then it becomes impossible to construct a flume owing to the lack of headway for the stream to pass beneath it, and if a level



PECOS CANAL. VIEW OF FLUME.

crossing or inlet is undesirable the canal must be passed under the stream in some form of culvert. An excellent example of such a structure is that used on the Arapaho canal in Colorado. As shown in Fig. 116, the canal is admitted to a wooden tank, composed of a plain wooden frame and lined with 2-inch planking. This tank is 5 feet in width and 10 feet in height. From it a wooden pipe 4 feet in diameter carries the water under the stream bed and discharges it into a similar tank on the opposite side, whence it flows on its course through the canal.

On the Fresno canal in California inverted siphons and culverts are frequently used in passing distributaries under railways or wagon roads, and in a few cases under other canals. In the latter case the smaller canal is taken under the larger one in an inverted wooden siphon, which consists of a simple wooden boxing of 2-inch plank, the amount of depression being but a few feet. In a few cases where the railways are in deep cuts the amount of depression is greater. The siphons used in these cases consist of two rows of sewer pipe 2 feet in diameter, terminating in brick walls at either end. These walls are 6 feet in diameter and 1 foot in thickness, and from them extend brick wing walls for about 5 feet until they reach the maximum width of the approaching canal. Another method in common use throughout California is to employ simple hydraulic mining sheet-iron pipe from 18 inches to 2 feet in diameter, which is carried under the obstruction as are the culverts just described.

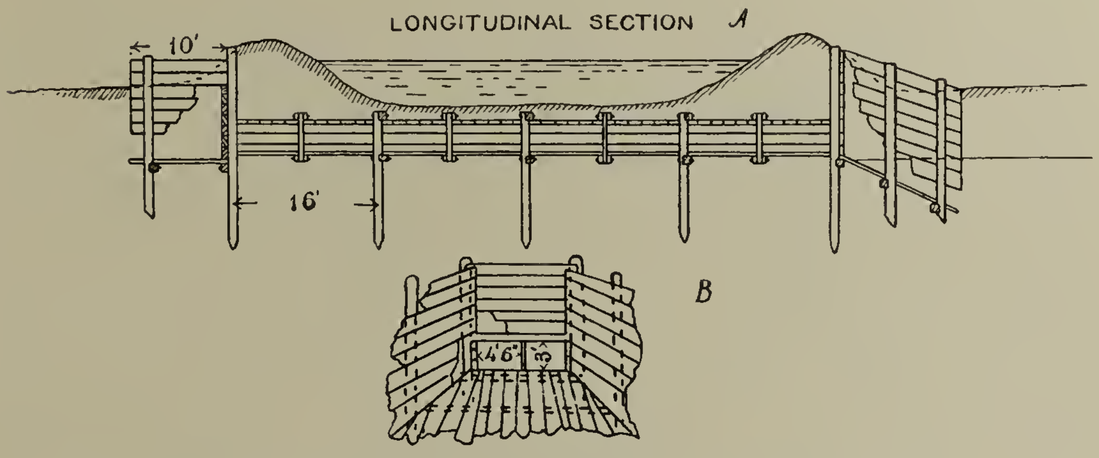


FIG. 117.—Del Norte canal. Cross section and end elevation of culvert.

A substantial form of box culvert is represented in Fig. 117. It is employed on the line of the Del Norte canal, in Colorado, to carry distributaries under other canals. This culvert consists of two parallel rows of square wooden boxing, each 4 feet 6 inches in width by 3 feet in height, and supported on piling and framed and braced with 6 by 8-inch scantling. The bottom and sides are floored with 4-inch planking and the top, which has to bear the weight of the superincumbent earth and water, is covered with 6-inch planking laid crosswise. A similar siphon is used on the Bear river canal on the Corinne branch, on which are five inverted siphons carrying small ditches under the canal. The largest consists of a double line of wooden culverts, the capacity of which is 70 second-feet. These culverts are constructed very much as is the Del Norte culvert above shown, each passage being 5 feet 8 inches in width by 28½ inches in height. The bottom is of 3-inch planking, while the sides consist of 8 by 8 scantling laid longitudinally one on the other and bolted together. The top consists of 8 by 8 scantling laid crosswise and firmly bolted to framing. The approaches are protected by flaring wings and an apron, a length of 7 feet of which is horizontal and on a level with the grade of the canal while the upper 7 feet is depressed to a depth of 22 inches.

The central irrigation district canal is carried under Stony creek in a very large culvert. The stream at this point is very wide and as a consequence the siphon is 650 feet in length, terminating in an inlet and outlet masonry well protected by substantial masonry walls and approaches. As shown in Fig. 118, this siphon or culvert consists of seven parallel lines of semicircular wooden tubing fastened under a horizontal wooden platform, the top of which is level with the bed of the creek. Above and below this platform in the creek bed is a cheap wooden apron, while some light training works have been found necessary in order to keep the current in its proper channel. At the inlet to the culvert are a set of simple flashboards regulating gates which act as an escape to the canal. The outlet culvert well is planned as a simple inlet to the canal. As shown in elevation and half cross-section the semicircular wooden culvert rests on a bed of concrete 1½ feet in maximum thickness, the upper end of the approach well having a row of sheet piling along its face to prevent seepage. The wooden culvert tubes are each 5 feet 5 inches in diameter and are composed of 2½-inch staves laid longitudinally and bound together by semicircular iron hoops terminating in bolts above the platform floor in such a manner that they can be tightened down and bound to it. These hoops are placed 2 feet apart and thus make the conduit a half barrel so far as its mode of construction is concerned. The platform to which these tubes are hung is framed with 6 by 8 timbers and floored with 4-inch planking.

The usual form of inverted siphons used in carrying canals across deep depressions where an expensive flume and trestle would have to be built is that shown in Plate CXVIII, and used on the line of the Phyllis branch of the Idaho canal. This consists of the Colorado wooden piping described elsewhere, and terminates in an inlet and outlet well at either end where it connects with the canal. These wells are simple wooden structures well framed and set into the canal banks. The wooden pipe rests on wooden shores founded on short scantling driven into the ground both in order to keep the pipe in alignment and to prevent it from sliding and breaking away. Similar inverted siphons are used in California, though the material employed is generally thin hydraulic mining sheet-iron pipe.

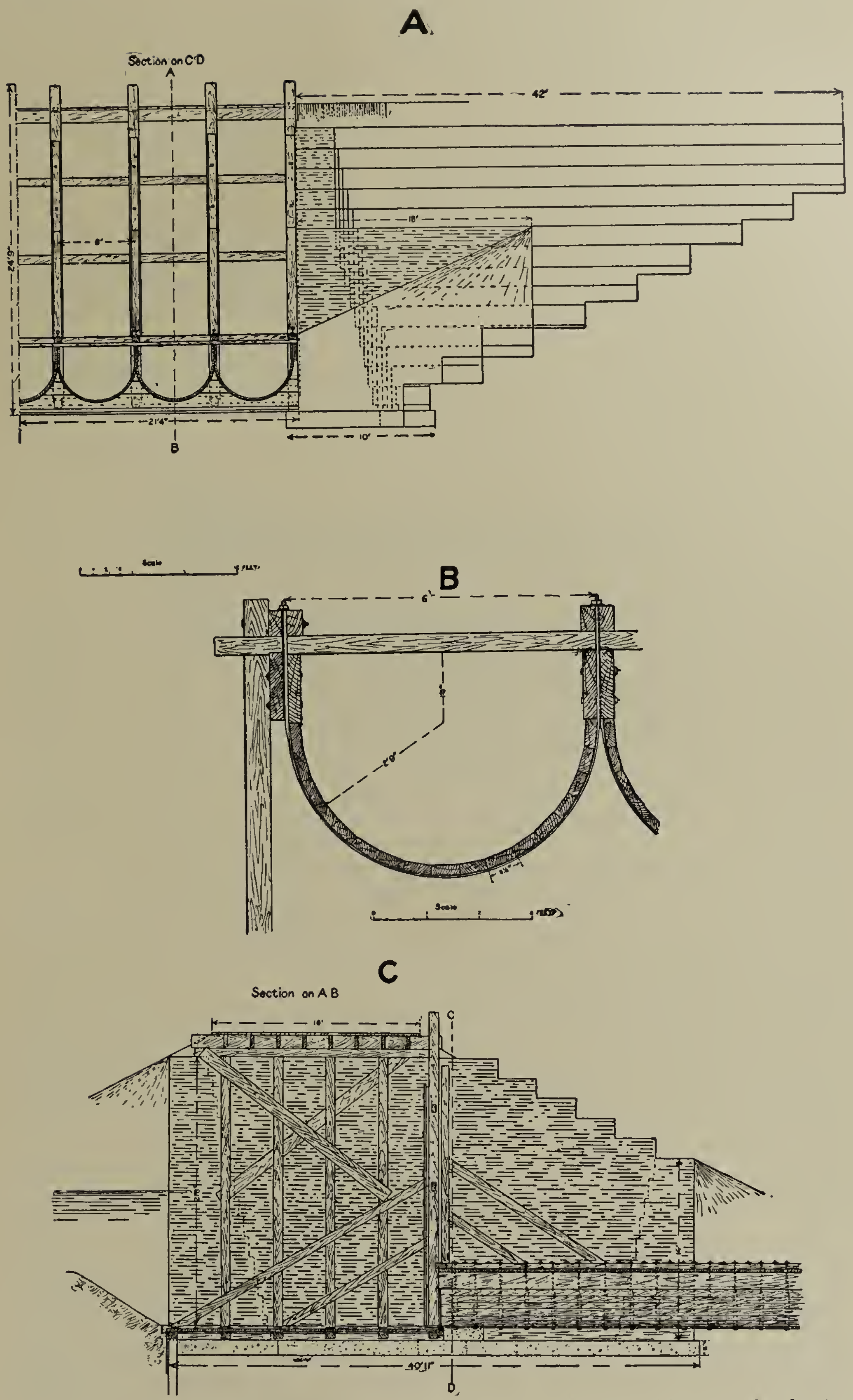


FIG. 118.—Central Irrigation District canal. Elevation and cross section of Stony creek culvert.

CHAPTER VI.

DISTRIBUTION AND MEASUREMENT OF WATER.

Distribution from the main canal is most economically effected when it runs along the summit of the interfluve or dividing ridge between two drainage lines. It can then supply water to branches or distributaries on either side of it, and a single check or regulator on its line may serve to divert water in both directions. This location is rare in the case of the main canal, but in the design of the distributaries and laterals it is the one most usually sought for by careful engineers. As yet little attention has been paid by American engineers to the design and treatment of distributaries and laterals. They have usually been aligned and excavated by some land surveyor or more likely still by the contractor. No especial attention has been paid to the rules governing the construction and alignment of canals nor to the obstacles to be encountered either in the quality of the soil or in the drainage lines to be passed. Skill and intelligent care in the alignment of distributaries, in the choosing of safe and permanent crossings of natural drainage lines, and in the proper maintenance of the surface level of the ditch in relation to the ground surface are as essential in a distributary or lateral as in the main canal. As shown in my report on Irrigation in India,[1] as much care is taken by Indian and European engineers in designing the distributary system as in the main canal, and great stress is laid upon the enormous losses of water which may occur in badly designed distributaries. The duty of water at the head of the canal may be reduced to half that the point of distribution, the loss being chiefly incurred in the distributaries and laterals.

In all well designed distributary systems the capacity of the channels is proportioned to the duty to be performed, the cross-sectional area being diminished as the quantity of water is decreased by its diversion to private water courses. A rule laid down by canal constructors, not only abroad but in this country, is to take off the distributary as near the surface of the main canal as possible. This is done in order that the bed of the distributary may be kept at as high a level as possible in order to permit surface irrigation throughout its length. In like manner, in order that the distributaries may be at a sufficient elevation above the surface of the land, it is often necessary to keep it in embankment throughout its entire length. Too little attention is paid to the disposal of surplus water in distributaries; these should always tail into some natural drainage line or other canal in order to avoid the loss of water which may be utilized. An ideal arrangement of a distributary system is one in which the main canal follows the dividing line of a water shed and the distributaries are taken off at stated intervals on either side and tail into the natural water courses.

---

[1] Irrigation in India, H. M. Wilson. Twelfth Ann. Rept. U. S. Geol. Survey, Washington, D. C.

Ordinarily the main distributaries as constructed in the West are laid out with some degree of care, and proper forms of regulating heads and falls are introduced on their lines. It is in the minor distributaries and laterals that the greatest negligence in design is shown and the great losses in seepage and evaporation occur. In a rough country or where water is valuable the common practice of constructing the distributaries as simple open ditches is being abandoned, and wooden flumes, sometimes iron flumes, or underground pipes are coming into popular use.

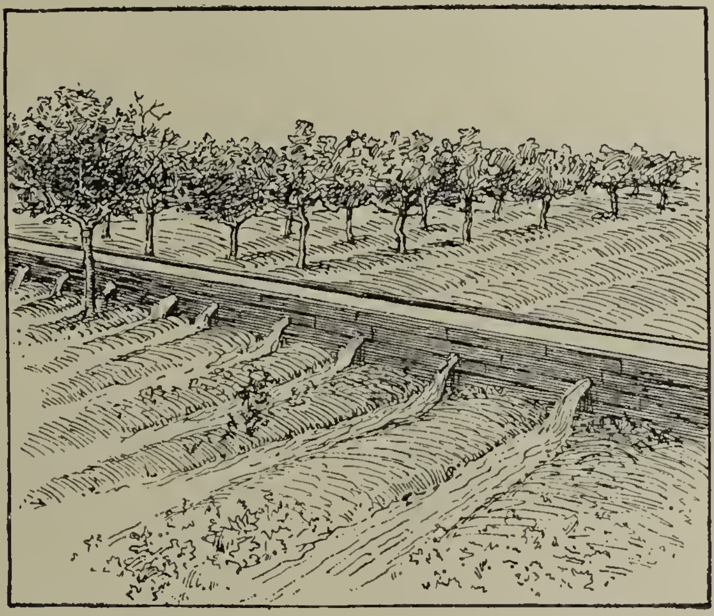


FIG. 119.—Water distribution. Riverside, California.

These latter will be described at length in another place, as they are deserving of especial mention. In San Bernardino valley, particularly in the neighborhood of Riverside, wooden flumes are commonly used for purposes of distribution. As shown in Fig. 119 these run down the even slope of the country through each 10-acre farm and have holes bored into their sides emptying into small ditches or furrows which lead water to the trees or vines. The holes are usually closed by wooden plugs or by a scrap of zinc which slides into place. The more careful farmers tar these flumes and frequently inspect them to see that no leakage shall occur.

One of the objections to the use of wooden irrigation flumes is the alternate shrinking and swelling of the wood and the consequent destruction of the structures. To overcome this difficulty and to provide a durable substitute an iron flume is sometimes employed. As shown in Fig. 120, a galvanized iron trough is used, supported in various ways according to the exigencies of the case, but generally by cast-iron brackets resting on timber supports. These Laybourn flumes may be of various depths and cross-sections.

Distributary heads are arranged much as are escapes along main canals. They consist essentially of two parts; a regulator or check below the distributary head on the line of the main canal in order to divert the water into the distributary, and the regulating gate in the head of the distributary to admit the proper amount of water to it. No method has as yet been employed whereby the water entering these distributaries can be measured, as in India, and the amount which the patrol considers desirable is admitted without any knowledge of what this quantity is.

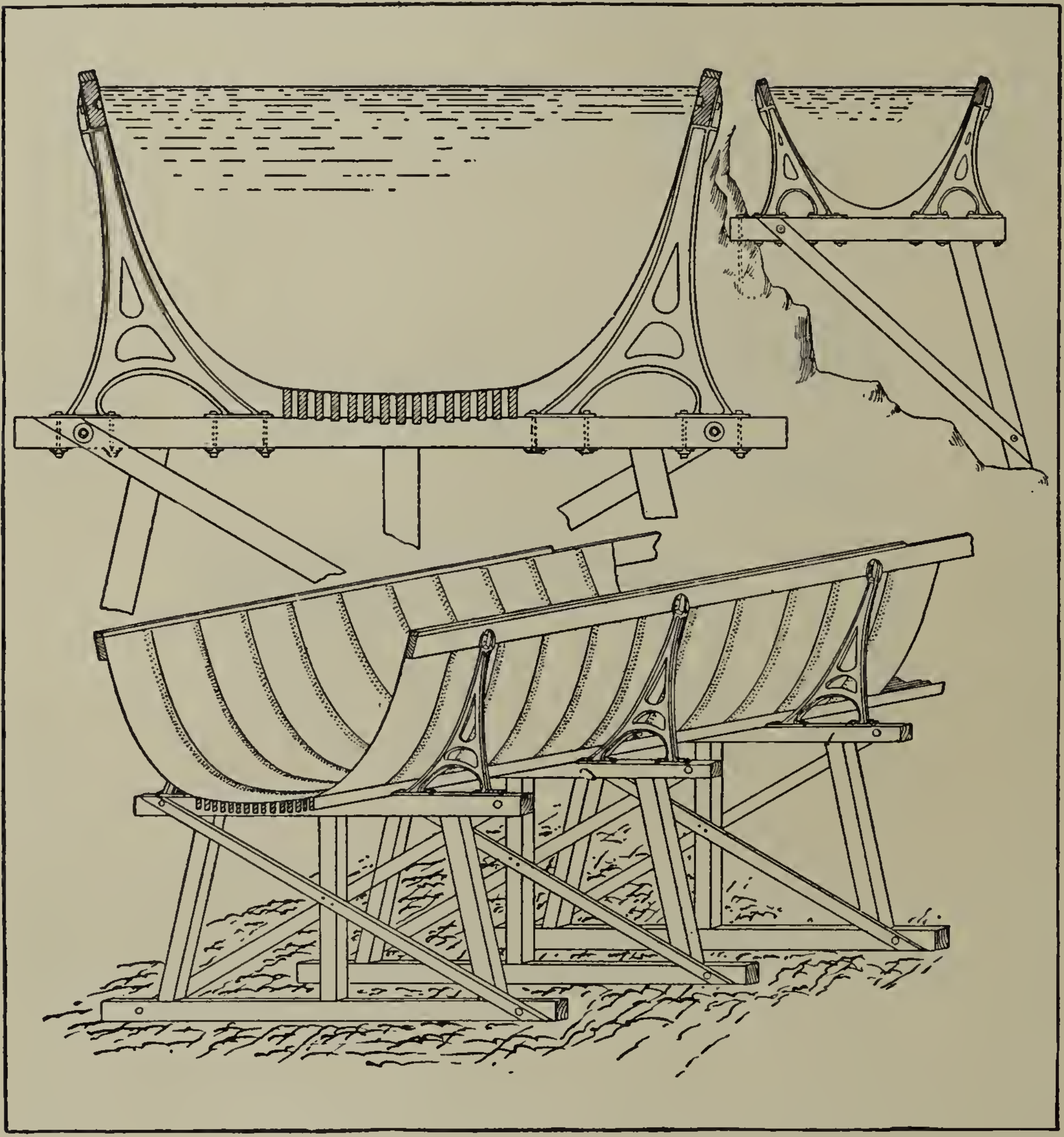


FIG. 120.—Laybourn iron flume. Perspective and cross section.

The ordinary distributary head consists of a wooden flume or boxing similar to the head regulator of the canal, the object being to protect the banks and bottom against erosion. In this flume is usually set a simple lifting gate, which can be raised or lowered to the desired height. In Fig. 121 is shown a distributary head on the line of the

Calloway canal, in California. The bed of the distributary is at a slight elevation above that of the main canal, and in the latter is placed an ordinary check regulator controlled by flashboards, while at the head of the distributary a sliding regulating gate is employed, placed at an angle of about 35 degrees. As there is a rapid flow of water through the head, a wooden check is placed in the flume a short distance in order to produce back currents and retard the velocity. Immediately below this is a minor head gate leading to a private channel, while a sort of well is again formed in the distributary flume just below this minor in order to retard the velocity of the current and the minor is closed by an ordinary vertical sliding gate.

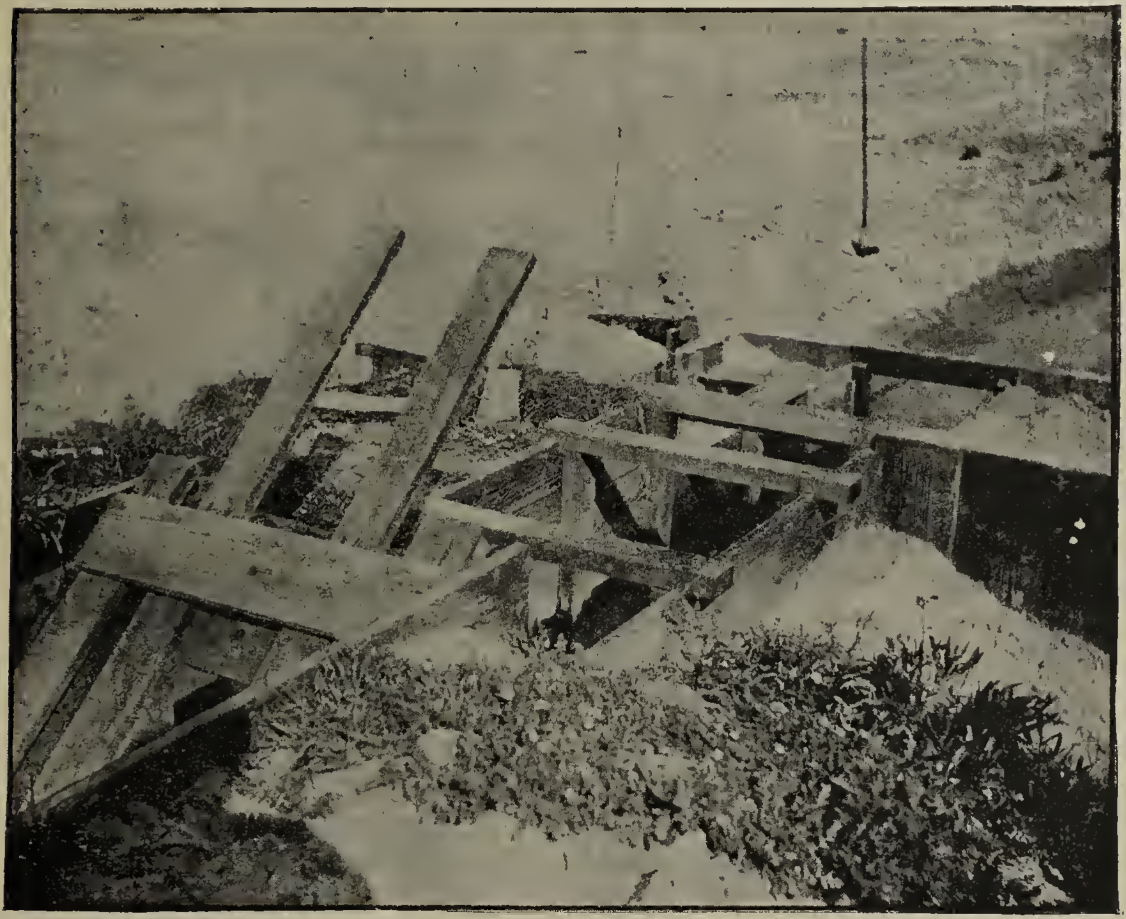


FIG. 121.—Calloway Canal. View of distributary head.

The distributary heads on the line of the Idaho canal are designed much as are the escape heads on the same canal. As shown in Fig. 101, they consist of cement pipes set into the canal bank at a point a trifle below the surface level, their inlet being closed by a sliding wooden gate set at an angle parallel to that of the canal banks, on which the gate and framing rests. These gates are operated by rack and pinion worked by hand. In very few cases is it necessary to construct regulators in the main canals opposite these distributary heads, and the volume of water in the main is always sufficient to fill the distributaries without this artificial aid.

By far the most important and interesting problem in connection with irrigation which yet awaits solution, not only in this country, but wherever irrigation is practiced, is that of securing a uniform and correct standard for the measurement of water. At present water is not sold as it should be, like other commodities which have value, per yard, pound, or gallon, though every engineer or canal-owner appreciates that such would be the most satisfactory manner of disposing of it. Owing to the difficulties of measuring flowing water at a cost commensurate with its value some other device has always been employed, such as charging a higher rental or a higher cash price for lands which have a water supply, or putting a charge of so many dollars per acre on the land served as a water right, or by some similar or equally unsatisfactory method whereby the amount of water going with the land is not specified, and remains always a point of contention between the purchaser and vender.

On this subject Mr. Walter H. Graves, one of the prominent irrigation engineers of Colorado, says:[1]

> The difficulties attending the measurement and allotment of water by reason of the constantly varying conditions and fluctuating head have given rise to a great variety of methods and customs; and in this respect, where system is all important and most needed, the absence of it is conspicuous. The most common practice in Colorado is by a sort of nondescript "inch unit," taken from a method of measuring common among miners in placer diggings, called "the miner's inch;" this in turn is taken from a module or unit of measure called the *oncia magistrale*, in vogue in the irrigating provinces of Italy, that was devised some three or four centuries ago by one Soldati. It is rather a method of subdivision than one of measurement. It is called the "statute inch," from an attempt to prescribe it by state statute; the very provisions of which, however, make the incongruity manifest. In practice it is impossible for the consumer to know how much water he is using. There is a great need throughout the entire irrigation region of a simple, practical, trustworthy apparatus for the measurement of water. The water meter employed in the water works of cities is too complicated to apply to the open ditches, where it may be choked with mud and weeds. The ingenuity of some engineer will be amply repaid for the invention of a hydrometric sluice that will meet the requirements of this demand.

The necessity of a better standard of measurement than the inch has given rise to the adoption as a unit of the "cubic foot per second," or, as it is more commonly styled, the "second foot" as the unit of measurement adopted by engineers. This unit has been incorporated in the irrigation laws of Colorado recently, and is now used in gauging streams and apportioning their waters among the several canals. Section 1813 of the General Statutes of the state of Colorado calls for the construction by the owners of ditches of a measuring weir or device for determining the volume of the flow of water, and the state engineer is compelled to compute this quantity and to furnish it to the water commissioners. Similar regulations have been enacted in the state laws of Wyoming and perhaps of other states, and a just appreciation of the necessity of legislation in this direction is becoming more general.

---

[1] Graves, Walter H. Irrigation and agricultural engineering, Denver Soc. of C. E., Denver, Colorado, June, 1886.

The method of measurement gaining in favor in Colorado is by means of a weir and the Francis formula. There are no insuperable obstacles to the measurement of water other than the expense attendant on careful measurement. Various devices have been described and invented for this purpose. One of the most ingenious and satisfactory for use on small distributaries is that invented by Mr. Foote.[1] The chief fault of this apparatus is the fact that it measures water by the inch instead of by the second-foot. This unit of graduation can of course be changed. Its merit consists in the circumstance that it renders it possible to maintain very nearly the standard head prescribed by the statutes over the opening. As shown in Fig. 122, A, it consists of a flume placed in the main lateral A and a side flume B, in which is constructed the measuring gate, while opposite to it is a long overfall C, the height of which is such as to maintain a standard head above the measuring slot. Such a weir is cheaply constructed and easily placed in position, and costs but a few dollars for a small service head. It needs no oversight or supervision, as it can be locked until a change of volume is desired. The irrigator himself can with his pocket rule at anytime demonstrate to his entire satisfaction that he is getting the amount of water for which he is paying. This form of measuring flume has been adopted on the San Luis canals in Colorado and in a few other places, and has proven most satisfactory.

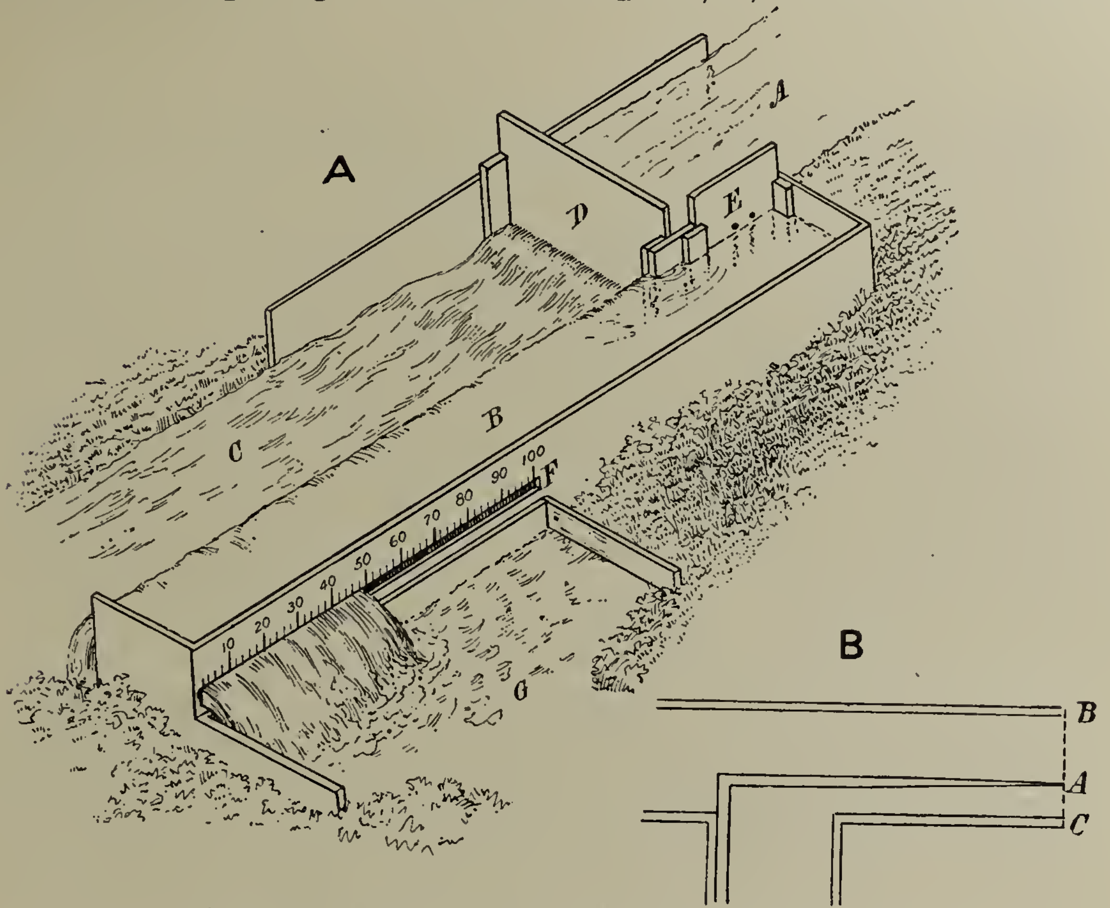


FIG. 122.—Foote's measuring flume, A; plan of water divisor, B.

---

[1] Foote, A. D. A water meter for irrigation, Transactions Am. Soc. of C. E., New York, 1887, vol. XVI. p. 134.

An excellent bulletin has been published on the measurement of water by the State Agricultural College of Colorado, from which the following extracts are made:[1]

In the measurement of water there are two distinct classes of measuring boxes different in their objects; one is the dividing box, whose object is to give each consumer some definite portion of the water flowing in a ditch; the other is the measuring box, which has in general for its object to give the consumer a certain definite quantity of water, as one second-foot. To this class of box the Italians have given the name "module," and French and some English and American writers have adopted the word. The word "devisor" is restricted by the author to the first class. In the case of divisors there is not a unit of measurement and none is needed; in the module, on the contrary, some unit is necessary.

Where it is required to divide the water into two or more equal parts the division becomes one of approximation only. The difficulty arises from the fact that the water has no uniform velocity across the channel. If, therefore, equal openings be made across the channel those near the center have the greater discharge. One form of divisor frequently used has a movable partition, as shown in Figure 122 B, so that the user who gets his water through the side channel can move the sliding partition *A* out to some distance, according to the amount of water required. In order to maintain an equal velocity, the water is brought to a state of approximate rest by a weir board of some height, 8 inches in one seen on the farm known as Union Ditch, in the San Luis valley, with a sharp crest on the upstream side. The partition board extends lengthwise of the ditch, and has its upper end sharpened. As the water passes over the weir it flows away in receptive ditches.

It is not possible to secure a module satisfactory in every respect or to meet all conditions. The conditions which have been considered the most important, judging from existing patterns, is that the flow should remain unaffected by variations in the level of the supplying canal. Nearly all the modules have attempted to furnish a constant flow. This can be done, first, by maintaining the pressure constant, the orifice remaining unchanged; second, by causing the opening to decrease as the head increases, and vice versa in proper proportion.

APPLICATION OF WATER.

Water is applied to the crops by several different methods, depending chiefly on the nature of the crop and the slope of the surface of the ground. These various methods are first, from filtration from a sheet of water downward through the surface soil; second, by lateral percolation from an adjacent source of supply; third, by absorption from a subsurface supply; and fourth, by absorption from water sprinkled over the surface.

The processes included under the first class are usually called flooding, and, in general, this is accomplished in three ways, depending on the character of the crop and the slope of the soil. These are (1) flooding of meadows, which consists in simply conducting a ditch along the upper slope of the land to be irrigated and turning the water down over this, permitting it to flow completely over the meadow and thus flood it; (2) flooding by checks, by dividing gently sloping surfaces into level benches by throwing up check levees and permitting the waters to stand on these as in still ponds; (3) flooding by dividing comparatively level country into squares or blocks by means of surrounding levees and letting the water stand in sheets in these.

---

[1] Carpenter, L. G. On the Measurement and Division of Water. State Agricultural College, Fort Collins, Colorado, October, 1890, Bulletin No. 13.

The second method of application is by means of ditches or furrows, and is performed generally in three ways: (1) By irrigating fruit trees and vines by running ditches close to them and allowing the percolation from these to moisten their roots; (2) by planting such crops as potatoes, corn, and vegetables in rows or furrows turned up by the plow and flowing the water in a small stream through these, thus gradually moistening the land on either side of the furrow; (3) by drilling grain in rows by machines making shallow furrows, or by making such furrows by means of projections from the surfaces of rollers and running the water through these furrows. This, like the last method, is practically a combination of flooding and sidewise soakage.

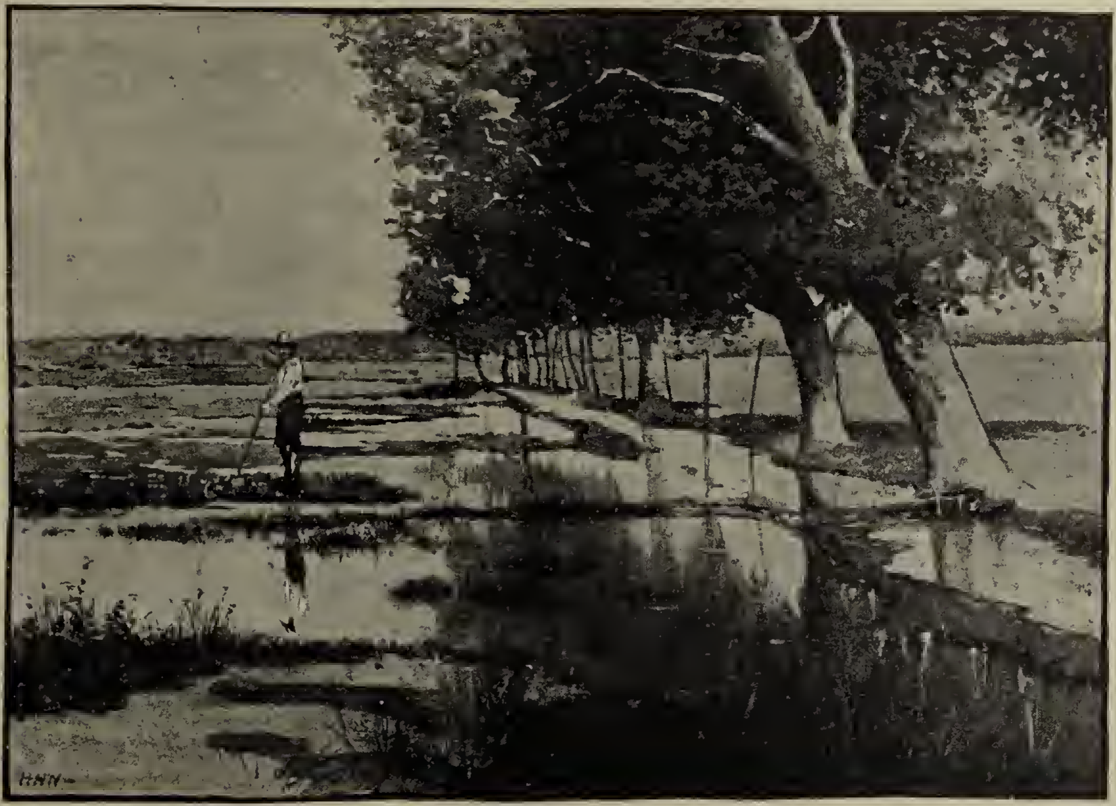


Fig. 123.—Irrigation by flooding.

The third method of irrigation is conducted by carrying pipes underground and having outlets to these under each separate fruit tree in an orchard, or so placing them that the water escaping from the underground orifices may irrigate vines near by. The fourth class, which includes all forms of sprinkling, requires no further discussion or description than to say that it may be practiced by hand or wagon sprinklers or by the simple watering pot or hose.

Irrigation by flooding is the most wasteful of water, but it is that most commonly practiced in the cultivation of grass and cereals. The flooding of wild meadow land by simply turning the water loose on it and letting it sink into the soil is a practice much to be condemned. (Fig. 123.) It is extensively employed in Montana and Wyoming and in some small portions of the other states and territories. Simple flooding on sloping ground is also extensively practiced on hay, alfalfa, and grain, the water being allowed to enter the field at its highest point in a ditch conducted around an upper contour of the field. Breaks are then made at intervals in the side of the ditch and the water is allowed to flow through these and find its way in a thin sheet if possible over the whole field. (Fig. 124.) The greatest quantity of water is required in this method of irrigation and it can be used on but few soils, as clayey soils will bake or parch under such treatment, forming a thin crust which kills or suffocates the growth of plants. When the slope is slight, shallow ditches are run from 50 to 100 feet apart in the direction of the fall. When the slope is steeper, they are made to wind around it on grade contours, and, as previously described, the field is inexpensively flooded by throwing up little dams in these from point to point.

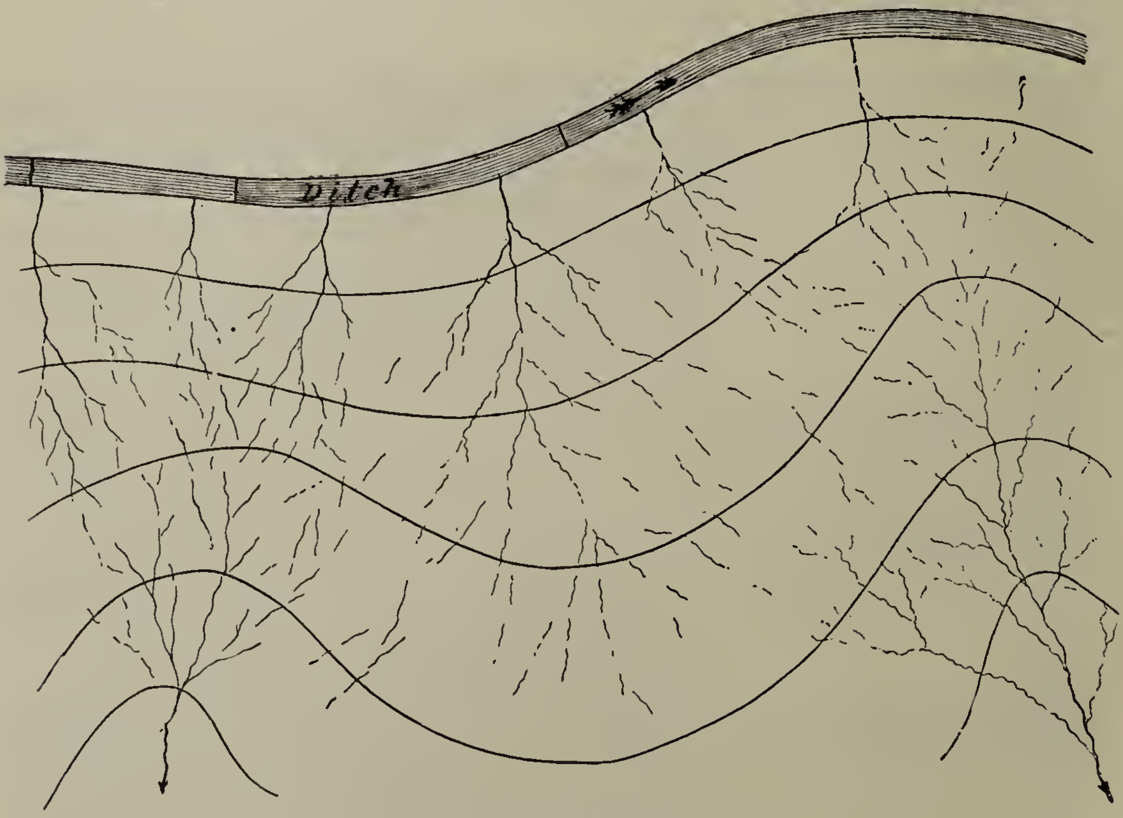


FIG. 124.—Application of water by flooding.

The method of flooding by checks is conducted in the manner shown in Fig. 125. Contour checks are carried around the slope of the land and consist of low ridges about one foot in height turned up with plow or scraper and at such distances apart that the crest of the check shall be about on a level with the toe of the check above it. The water is then run through the ditches, and admitted by the gates into each separate check. When the check is full the water is drawn off to the next lower level, or, if the soil is porous, is allowed to stand until it has been absorbed. If these checks are properly thrown up with scrapers they will last for many years, and the field may be plowed and replowed without the destruction of the checks or their in any way affecting the handling of the crop. The area included within any check must be so proportioned to the volume of water that the absorption will not exceed the supply, otherwise the water would only spread over a certain area. Where the soil is compact the area of the check is made much larger than if it is absorbent. In some portions of the Calloway canal system the distributary ditches are placed as much as a quarter of a mile apart and their banks form two of the bounding ridges or levees of the check, the third or lower boundary being the contour levee connecting the canal levees. The less the height of this lower check the better, because the quantity of water spread over the land will be of a more uniform depth and will interfere less with plowing and harvesting, and the greater the width of the base the better. From 6 inches to 1 foot has been found the best height, with a base of 10 to 15 feet.

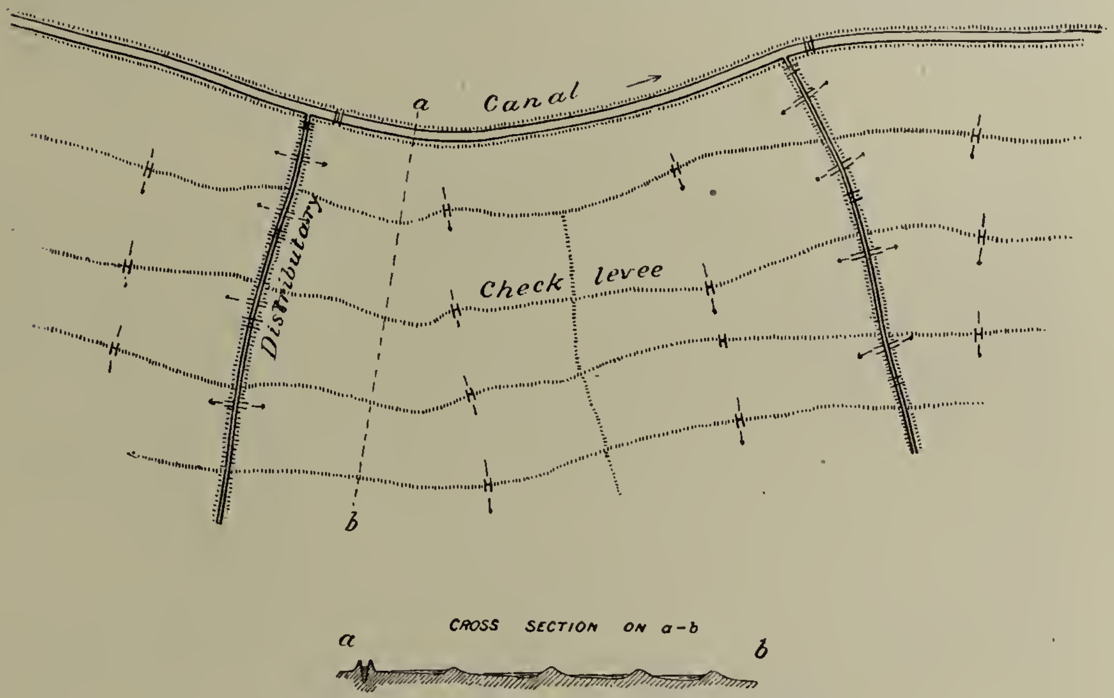


FIG. 125.—Application of water by check system.

The cost of preparing the land for checks varies considerably with the character and slope of the ground and the experience of the irrigator. The following is the cost of repairing some of the best constructed check levees seen in California. These are on the Calloway canal in Kern county:[1]

The average cost per acre of 5,956 acres prepared in this way was as follows: Earth work, $1.64; waste or drainage gates, $0.51; total, $2.15. The average cost of lateral canals, including the necessary regulators and side gates, was $4 per acre, making the total cost of preparation of ground $6.15 per acre.

The check levees are built on 1 foot contours with 20 feet base. The lateral canals are from one-fourth to one-half mile apart and the checks range from 10 to 50 acres in area. From 12 to 20 miles of check levees are required per square mile of check, and a mile of levee contains 3,080 cubic yards. As the soil is a sandy loam easily worked the cost of preparation as shown above is probably a little less than the average cost of such works elsewhere.

---

[1] Schuyler, J. D. Appendix B. Report of state engineer of California; Sacramento, 1880; pt. 4, p. 85.

Flooding by squares is practiced, especially in southern Arizona about Tucson and Phœnix, where the slope of the surface is comparatively level. The fields are divided in blocks of from 20 to 60 feet on each side (Fig. 126), which are separated by ridges about 10 inches in height, through which openings are made leading from one square to the other. In some cases the fields are divided into much larger squares, sometimes nearly an acre in extent, depending on the slope of the ground. The water is admitted to each of these and is permitted to soak into the soil. This method is more generally practiced on alfalfa and hay crops.

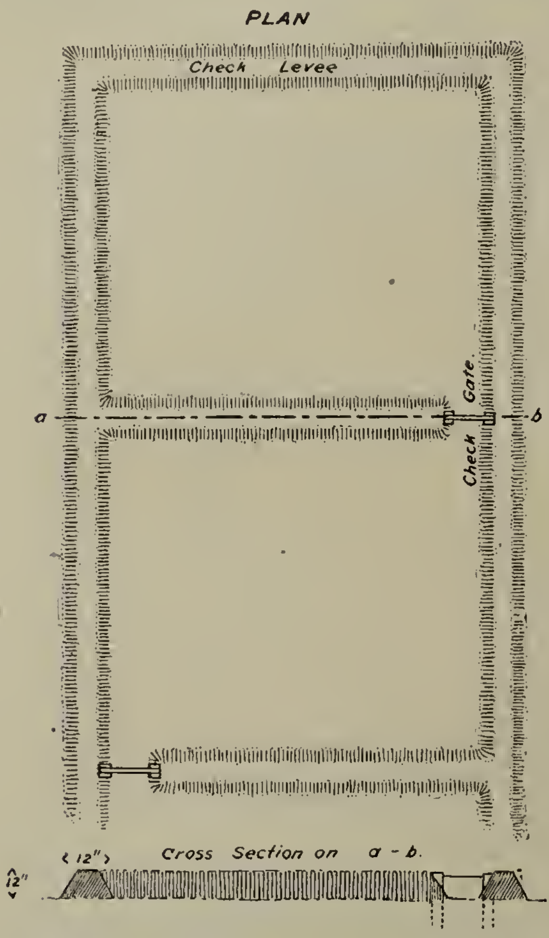
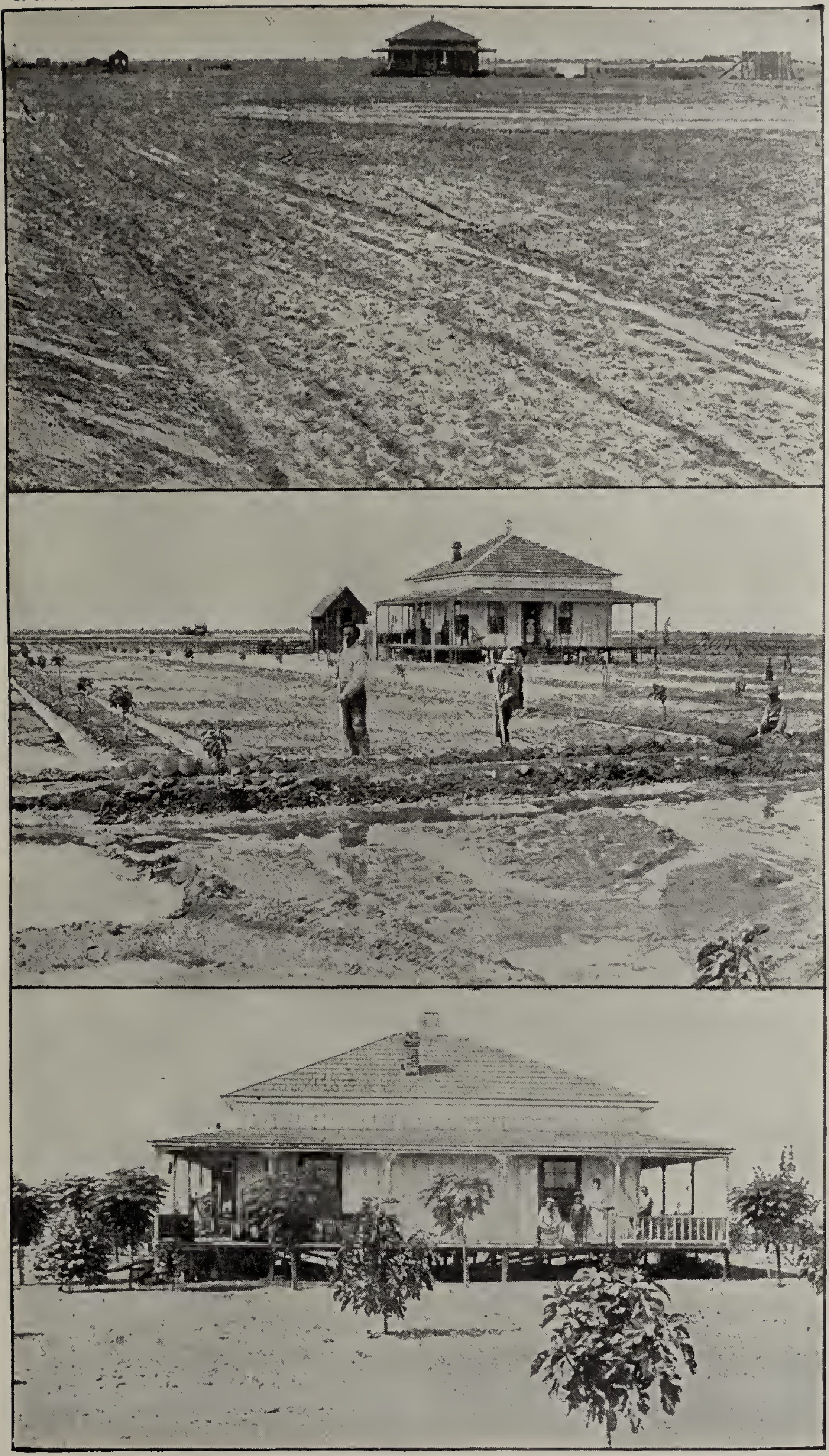


FIG. 126.—Application of water by block system.

Potatoes, corn, vegetables, vines, and fruit trees are irrigated by furrows. Grain is sometimes irrigated by the same method, the field being laid off by means of ditches plowed along the upper slopes, from which radiate diagonally downward across the slope shallow V furrows, in which the grain is sown by machine drill. As shown in Fig. 127, this method may be practiced by running the main ditch on the upper slope of the field and running the main plowed furrows down the slope. Water is turned into these, a few at a time, by blocking the ditch with a clod of dirt or a board. In an irregularly sloping field the furrows may have to run at various angles in order to catch the right grade. Irrigation by furrows is sometimes practiced in grain fields by rolling these, after the grain is planted, with a heavy roller having annular projections from 1 to 2 feet apart, which make grooves in the surface of the soil in such a direction that when a stream of water is admitted to these grooves a constant flow is kept up through them as in plowed furrows. The number of applications of water to grain and vegetable crops differs so greatly, according to climate, that it is difficult to make any fair statement regarding this. Where flooding is practiced in checks anywhere from 2 to 14 inches in depth of water is laid on at a single watering. These may differ in number from 2 to 5 in the season, according as it is practiced in southern California, in Arizona, or in Montana. In irrigating through furrows an equal diversity occurs; the water is run on generally for 12 hours at a time, and from 2 to



ORCHARD IRRIGATION BY SIDEWISE SOAKAGE FROM DITCHES.

5 times in a season. It is found advantageous to run the water on for some time in autumn and early spring before plowing; this soaks the soil thoroughly and causes it to require less irrigation after the crops are planted.

When flooding is practiced in orchards it is found to bring the roots to the surface and thus enfeeble them. In consequence of this furrows are run from the upper ditches generally in double rows, one on either side of and at a short distance from the trees or vines, as shown in Fig. 119, or branch ditches are run at a short distance from the trees (Pl. CXXXIX.) By this means the water percolates into the soil and reaches the roots of the trees at some depth beneath the surface, thus moistening and encouraging their growth. Plate CXXXIX shows the progress in growth of an irrigated orchard in Kern county, California. The first view was taken in March, 1891; the second in June and the third in September of the same year. The common rule, when flooding is practiced, is to protect the trees by simple ridges so that water does not affect the surface within 3 or 4 feet of them. Oranges and olives are watered three or four times in a season; vines once, twice, and often not at all after the first few seasons, depending on the soil and climate. It is frequently found that whereas five waterings used to be applied to orange orchards, it has been possible to diminish this number to one or two waterings in a season, and may be to none at all after the trees have gained a healthy growth. Experience has proven that the more thoroughly the soil is cultivated the less water it requires, doubtless largely owing to the fact that evaporation is less from broken than unbroken soil. However this may be, it is well established now that where liberal tillage of the soil is practiced fewer waterings are necessary.

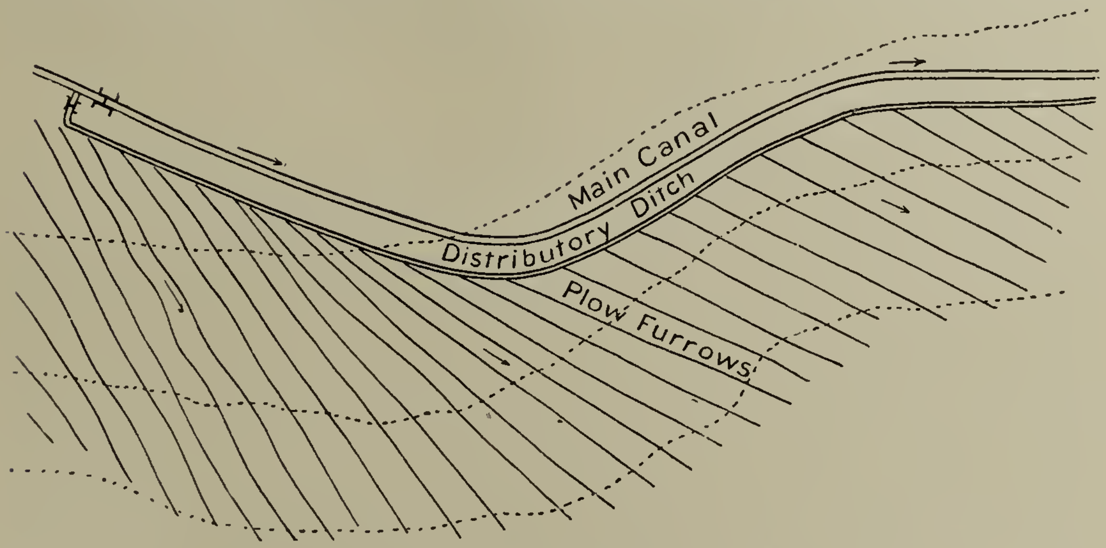


FIG. 127.—Application of water by furrows.

Perhaps the most ingenious and economical method of applying water to trees or vines by furrows is that employed at Riverside, California, and described in detail in the Irrigation Age.[1]

---

[1] Van Dyke, T. S. Riverside: Mode of Irrigation. Irrigation Age, Denver, Colo., 1891. Pp. 81, 101, 161.

The end sought when the Riverside agriculturist irrigates his land is, to put ground in the condition resulting from several days of long soaking rain, rather than in the condition resulting from a small cloudburst, which is the condition following most methods of irrigation. This condition can not be brought about by flooding or by running large streams of water through furrows or ditches for a short time, but is attained by running small streams of water for a long time. This is accomplished, as shown in Fig. 119, by running a number of plow furrows between the separate rows of trees. These trees are from 18 to 20 feet apart, and the nearest furrow is not closer than 3 feet from the trees and the furrows are from 2 to 3 feet apart. Each of these streams has a volume not exceeding one-four-hundredths of a second-foot. They are run from two to three days at a time and thoroughly and evenly soak the soil. This system of small streams running for a long time is generally applied to trees and vines, but it has been tried on other crops sufficiently to show that it can be used for nearly any of them where the soil is not too loose. The results with corn and grain have been excellent.

In order to make this method successful the laterals which run from the main distributary to the fields and from which the small furrows are filled should be uniform to a degree that can not be secured by delivery from an open earth ditch. This is accomplished by running wooden laterals or small box flumes along the surface of the ground at right angles to the rows of trees at proper intervals. It has been found that these can be built and placed complete for about $50 per 10-acre tract. These flumes are usually coated with tar to prevent their decay. On the side toward the furrows auger-holes are bored near the bottom board at intervals, and the water escapes from these directly into the furrows and runs down the latter between the trees. Such a flume 8 inches square is generally large enough for 10 acres, providing the grade is sufficient to produce a good velocity. The flow through these holes is regulated by wooden buttons or plugs, which are inserted when it is desirable to cut this off. These flumes are of such dimensions that they will carry about one-half a second-foot. When the slope of the ground is great this is neutralized by breaking it into steps or falls. Not only does this method produce superior results, but it uses less water and requires less labor than the ordinary methods and the duty of water has been found to be far greater than under the ordinary system of applying it. By letting the water run for a sufficiently long period of time at each watering, most fruit trees thrive well on from three to five waterings; vines rarely need more than two waterings, and apricot and deciduous fruits will do well on the same number.

Irrigation from beneath the surface, or subirrigation, if not excessive, is considered the most perfect method of supplying water to plants. The method is to replace soakage from above, through flooding or furrows, by absorption from below, which to be perfect should not wet the surface. This is now extensively employed in southern California in the irrigation of orange and olive trees and of vines. It is effected by replacing the ordinary furrows of surface irrigation by pipes laid under the ground. These are taken from the distributaries, which are usually sheet-iron or steel pipes. The expense of preparing a piece of land for such irrigation is relatively great, but is more than repaid by the saving in water charges where these are high, since the resultant duty of the water is relatively great, reaching ordinarily from 500 to 1,200 acres per second-foot. In the neighborhood of San Diego and San Bernardino, where the land is prepared by irrigation companies, it is laid off and sold in 10 or 20 acre lots and the company brings a distributary pipe to the highest point in every lot. From this the cultivator lays his pipes as he desires. These pipes are laid at a depth of 1 to 1½ feet below the surface, parallel to the rows of trees or vines in the orchard.[1] In them, on the upper side, is inserted a wooden plug opposite each tree or vine. Each plug is surrounded by a larger standpipe, setting loosely on top of the distributary pipe, open at the bottom and reaching to the surface of the ground, for the purpose of keeping the outlet free from dirt and rendering it accessible at all times for inspection. The process of irrigation consists in simply turning the water off or on from the main pipe, the water finding its way through the outlets, filling the standpipes and slowly percolating to the surface of the plant.

This earlier system has been much improved upon in later years. Glazed earthenware pipes are now more generally employed and ingenious methods of measuring the amount of water used and of locking the valve leading to each individual distributary are employed whereby the company is enabled to sell the water by measurement. By this method of irrigation plants do not receive the fertilizing elements brought to them by surface irrigation, but the pipes act as drains to carry off any surplus water and thus prevent the rise of alkali and the other evils attendant on oversaturation. As no water appears on the surface the ground does not bake with the heat of the sun and is kept warm and moist, as the temperature is not reduced by evaporation.

MAINTENANCE AND SUPERVISION.

Proper care and consideration have not been given by American engineers to the questions of the maintenance and supervision of canals after construction. To begin with, the necessity for these is much greater in this country than elsewhere, owing to the cheap and temporary character of construction, whereas the expense should be higher and the attention greater. In India and in Europe permanent establishments for the maintenance of canals are kept up. An engineer and his assistants are retained in the permanent employ of the operators of the canal the same as if it were a railway. In addition to these are superintendents or overseers of divisions, under whom are patrols. These keep a vigilant outlook for violators of the law, for trespassers on the canal property, and for injury or deterioration in the structures. While the expense for salaries and supervision is high, it is more than saved in the diminished cost of reconstruction and maintenance.

---

[1] Schuyler, James D Appendix A, Report of State Engineer of California. Sacramento, 1880. Pt. 4, p. 45.

With us as soon as the construction of the canal or irrigation work is completed the services of the engineers are dispensed with and the work of supervision and maintenance falls to the lot of a few water masters or patrols whose divisions are too great for their proper inspection even if they were competent to appreciate the necessities for repair when they occur. There is no good reason why as much care should not be exercised in the proper supervision of canals as is employed on railway lines. The roadbed and rolling stock of a railway might be allowed to deteriorate for some time without seriously impairing the operation of the road, but deterioration in the works or channel of a canal means speedy paralysis and perhaps the loss of thousands of dollars to the agriculturists who depend upon its water supply.

The sources of impairment of canals are (1) the erosion of the canal banks by water; (2) the filling of the channel from deposition of sediment; (3) the erosion of the outer banks due to storm and flood waters; (4) damage by cattle, horses, and trespassers walking over the banks; (5) injury or destruction of the head works, as the dam regulator or escape, by floods; (6) incendiarism; (7) decay in the timbers forming structures; (8) destruction of the banks due to the burrowing of gophers, and (9) the choking of the channel by weeds and water plants. The first and second causes of impairment may be diminished by the employment of intelligent engineering skill in the proper alignment and construction of the canal, and by the vigilance of patrols in early discovering and repairing all effects of erosion. If the deposits of sediment are large they will have to be removed by dredges or scrapers when the canal is not in operation or some changes will have to be made in the head works or slope of the canal to rectify them. The injuries to the banks of the canal from the third cause should be very small if the canal was properly aligned in the beginning and ample provision made for drainage channels. Injury to the banks from rain may be counteracted by encouraging the growth of grass and trees. Injury from the fourth cause can be prevented by fencing or by the vigilant execution of laws against trespassing.

Damage to the canal from the fifth and seventh causes may be provided against by building the structures of some permanent material and by proper supervision and the immediate repair of weakened parts. It is customary on the canals of the West to maintain at all sites of bridges, regulators and other works small piles of lumber on which the patrol may draw for the repair of these when necessary. It is difficult to indicate any way of making provision against destruction by incendiarism. Large canal companies have found the losses from this cause to be an item of considerable importance. The destruction of bridges, regulators, and other works by ordinary fires may be prevented to a certain extent by plowing around them to prevent the spread of prairie fires and by vigilance on the part of the patrol.

Much annoyance and damage result from the burrowing of gophers or moles. They dig into the banks or canals or into earth dams, often traveling long distances and completely honeycombing them. When they reach the water sudden and hidden leaks occur and result in washing out considerable portions of the structures. On the lines of the Arizona and Del Norte canals the writer has seen many evidences of damage done by these animals, and much expense has been incurred by the washing out of considerable lengths of the canal bank, and the loss to the farmers has been large from failure to get water at the proper time. Considerable losses in the discharge of canals are produced by weeds. In deep canals these grow only in the shallow water near the banks. Willows and other water plants along the banks encroach upon the water space and diminish the discharge. The only way in which this can be prevented is by pulling up or mowing down the brush at the proper time, though perhaps it may be necesary to draw the water completely from the canal in some instances in order to let the sun kill the water plants.

It is often necessary in rivers which are subject to high floods to protect the diversion weir and regulating gates and other head works by means of floating booms thrown across the river above the head works to protect them against damage from logs, trees, etc., which the current brings down. At the head of the Del Norte canal and in a few similar structures, gridiron booms or fences have been erected to prevent the admission of logs and timber to the gates. In the maintenance of flumes the greatest cause of destruction and deterioration to be provided against is leakage. If they have been properly constructed they may be cheaply maintained by overhauling them early each spring before the water is admitted and driving home any loose planks and caulking cracks and seams with oakum.

On the few western canals where any attention is paid to the proper maintenance and supervision, the canal is arranged in divisions, each under the charge of a superintendent or ditch rider. Both the Arizona and Del Norte canals maintain an engineer and assistants constantly employed in making changes, improvements, or additions to the property, and under them are men in charge of the head works, locally known as gate keepers, and superintendents or "ditch riders," as they are called. The divisions of these latter are regulated in length by the number of irrigation outlets and the character of their works, and the length of these divisions is such that the rider can visit every portion of them daily. The addition of a telephone service in a few cases has added considerably to the proper maintenance of canals. By these means the engineer or superintendent is kept constantly informed of the condition of the works and can at once visit those which need attention.

CHAPTER VII.

WATER STORAGE.

The storage of water to supplement the flow of intermittent streams and thus increase the amount available for irrigation during a certain short period of time has been practiced in this country as long as has irrigation from perennial streams. The object of storage works is to assure a constant supply of water during the irrigating season regardless of the amount of rainfall. Where great perennial streams flow through land to be irrigated there is ordinarily no necessity for the construction of storage works, as these streams supply sufficient water for the irrigation of the land. Where, however, there are areas of irrigable land which can not be commanded by canals from perennial streams they may be irrigated by the construction of storage works. These will catch the intermittent flow of the minor streams and retain it until wanted. Storage works are also of value in conserving flood or waste water from large streams, thus adding to their value for irrigation.

Works for storage purposes are divided into various classes according to the character and location of the storage basin and of the retaining wall or dam. Under the former subdivision are, first, natural-lake basins; second, reservoir sites situated on natural drainage lines, as in a valley or enlargement of a canyon along a stream or river; third, reservoir sites situated in natural depressions on bench lands or plains back from the main drainage lines; fourth, reservoir sites in part or wholly constructed by artificial methods.

Reservoir sites of the first class are usually the best and cheapest. Ordinarily a short drainage cut or a comparatively cheap dam, or both, will give a large available storage capacity. Among sites of this kind may be mentioned Eureka lake reservoir in California, the construction of which cost $2·50 per acre-foot; Lake Eleanor reservoir, in California, which is estimated to cost $2·10 per acre-foot; Twin Lakes reservoir in Colorado, the cost of which is estimated at $2 per acre-foot; Jackson lake, Idaho, which is estimated to have cost 20 cents per acre-foot; and a few others of the same kind, all of which are among the cheapest and most desirable of reservoirs.

Reservoir sites of the second class include those which are most common. They are usually the most expensive, owing to the precautions necessary in building the dam in order to effect a discharge of the flood waters. Among the more important of this class are the Sweetwater reservoir, which cost $40·90 per acre-foot; Bear valley reservoir, $5·30 per acre-foot; Cuyamaca reservoir, $9 per acre-foot; Boman reservoir, $11·18 per acre-foot; and others, for which estimates have been made, ranging from $4·50 to $13·50 per acre-foot, stored.

Of the third class of storage sites many hundreds are to be found on the plains east of the Rocky mountains in Colorado and Wyoming, and on the bench lands of Montana and in the foothills of the Sierras in California. Usually the construction of these is comparatively inexpensive, as the natural depressions can be converted into reservoirs by a deep drainage cut or a comparatively cheap earth embankment. No provision is necessary for the passage of flood waters, as there is no catchment basin adjacent to the site. One heavy item of expense, however, is the supply canal to convey water from some adjacent stream. Several reservoirs of this type have been constructed in various portions of the west, notably, one on the line of the Florence canal in the Gila valley in southern Arizona; the Benton reservoir on the line of the projected Sun river canal in Montana, and several on the line of the Colorado Land and Water Company's canal and other canals in Colorado. These have each cost less than $1 per acre-foot stored.

Among the last-named class of reservoirs are those which may be built chiefly or wholly by the erection of earth embankments above the general surface of the country or by the excavation of reservoir basins. These are not worthy of consideration in this report, as they are very small, and usually built for the service of small tracts of land, such as the wooden or earthen tanks to conserve the waters of artesian wells in Dakota and California, or the small tanks employed with the underground pipe systems of southern California.

The second great sub division of reservoirs, that depending on the character of the dam, may be also divided into several classes. These are, first, earth dams, such as those closing the Cuyamaca and Merced reservoirs; second, combined earth and loose rock dams, like that employed at the head of the Pecos canal; third, the hydraulic mining type of dam, constructed of a combination of logs and crib work, and loose rock dams with planked face, like the Fordyce dam in California, and the Walnut grove dam in Arizona; fourth, masonry dams like those closing the Sweetwater and Bear valley reservoirs in California. In addition to these are two slightly different classes of works, like the loose rock dam with masonry facing, an example of which is that closing the Castlewood reservoir in Colorado, and the simple regulating gates, which are practically dams, used to close the outlet cuts to depressed basins, as at Benton lake reservoir in Montana.

The first three classes of dams should rarely be constructed on streams which are subject to high floods, and then only when sure and ample wasteway can be provided. The last two classes should likewise be constructed only where sufficient and safe spillway for flood waters can be provided, though dams constructed wholly of masonry may be built with the intention of permitting flood discharges of any volume to pass over them, in which case they should be given a cross section of additional strength to provide against the shock of the overflowing waters. Such dams have been built to close the Vyrnwy reservoir in Wales, at the head of the Turlock and Fulsom canals in California, and at the Betwa reservoir in India.[1]

Since the passage of the act of Congress signed October 2, 1888, providing for the survey by government engineers and the withdrawal from occupation of lands included within reservoir sites, and since the passage of a subsequent act, approved March 3, 1891, regulating the methods of disposal of these reserved storage sites, the growth of the popular interest in the subject of water storage in the west has led to the development of a great number of storage projects, a few of which are already under construction. Many of these are within themselves excellent and feasible projects and will some day be undertaken, while a large proportion will in the course of time prove impracticable and be abandoned. These laws have been quoted in another part of this report, while the lists of reservoir sites selected and their location are given in detail in Eleventh and Twelfth Annual Reports of this Survey.[2] According to the second of these reports 147 reservoir sites were located and surveyed in the year ending June 30, 1890, their aggregate capacity amounting to about 2,500,000 acre feet.

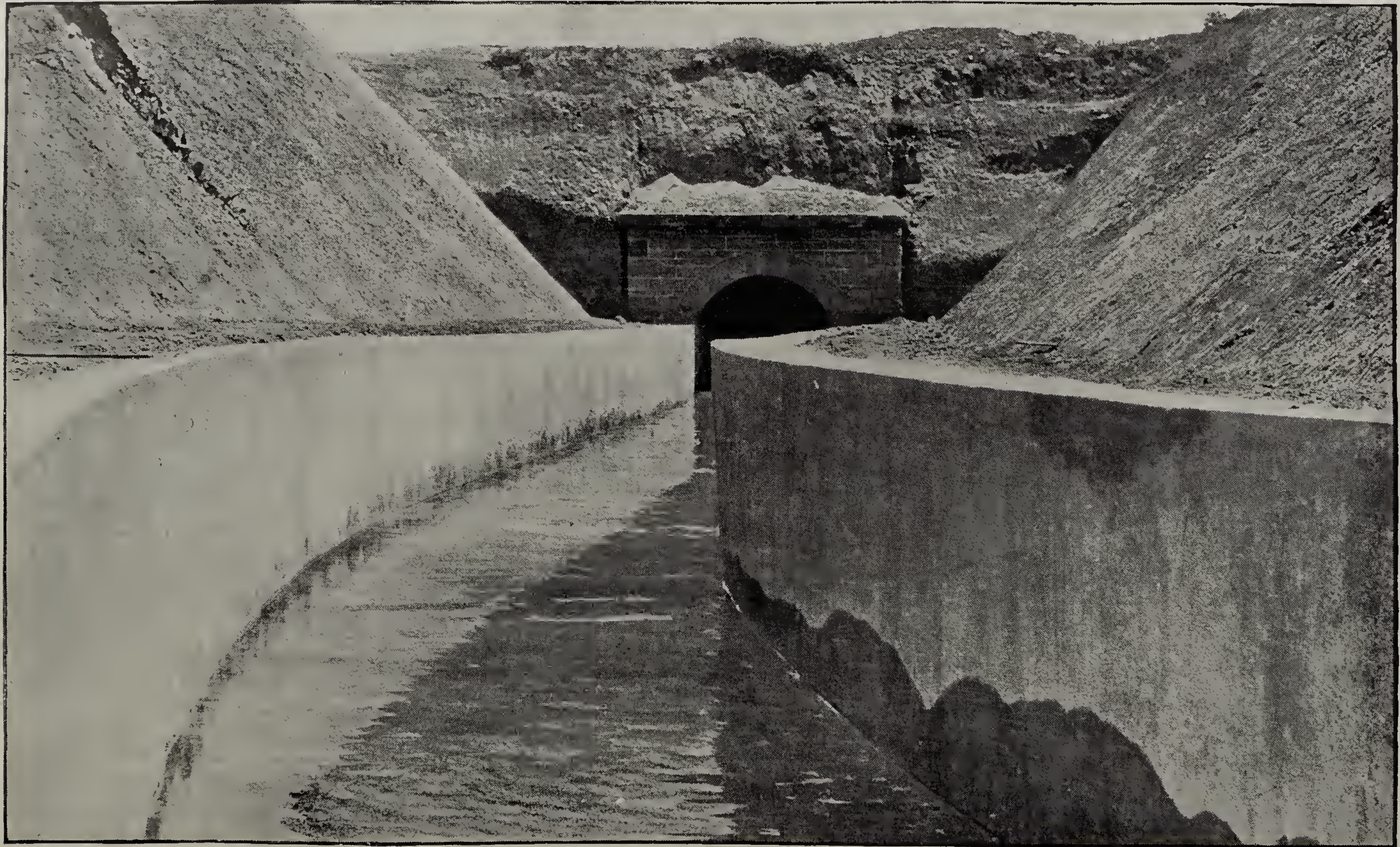
SAN DIEGO FLUME COMPANY.

The reservoir and canal system of this company is excellently planned and contains nearly all of the typical features of a combined storage and irrigation system. It consists of the Cuyamaca storage reservoir situated high in the Coast range and of the bed of the San Diego river, down which the storage waters flow for some distance before they are diverted by a pick-up weir to the flume, which conducts them to the irrigable lands. A supplementary reservoir has been projected on Dye canyon from which waters will be carried over a drainage divide and added to that coming from Cuyamaca reservoir, while still another reservoir for distributive purposes has been projected on the irrigable land for the purposes of storing superfluous waters which may be brought down by the flume. Cuyamaca reservoir is closed by a great earthen dam and at the head of the flume is a masonry diverting weir. There are in all about 36 miles of wooden flume and trestle and several tunnels and some lined masonry channel.

---

[1] Wilson, H. M. Irrigation in India, Twelfth Ann. Rep., Part II, U. S. Geol. Survey, Washington, D. C. 1891.

[2] Thompson, A. H. Report on the Location and Survey of Reservoir Sites, Eleventh and Twelfth Annual Reports U. S. Geol. Survey, Part II, Irrigation, Washington, D. C., 1890-'91.



SAN DIEGO FLUME. VIEW OF TUNNEL AND APPROACH.

Cuyamaca reservoir is situated in the Coast range about 70 miles east of San Diego, California, at an altitude of 5,500 feet. This work is the property of the San Diego Flume Company, organized in 1886, to bring water from the high mountains for the domestic supply of San Diego and to irrigate ranches in its neighborhood. The storage reservoir has a capacity of 11,500 acre-feet and from it the water is turned into Boulder creek, down which it flows for 12¼ miles with a fall of 4,000 feet to the main diverting weir, the altitude of which is 800 feet. Owing to the scarcity of water in this neighborhood the canal which heads above this weir is not in open excavation, as the loss by evaporation and absorption in an earth channel would be too great, but it is a wooden flume 36 miles long, built for most of the distance along the steeply sloping canyon sides of the San Diego river and requiring a number of trestles and tunnels to cross side drainage channels or to pierce long bends which would have greatly increased its length. In all there are 315 trestles, varying in height from a few feet to 85 feet, the longest being that across Los Coches creek 1,794 feet in length, an illustration of which is shown during construction in Pl. CXXXVII. On its line are also 8 tunnels pierced in rock or earth, with lengths varying from 91 to 1,901 feet, their total lengths being 4,190 feet, with 4,760 additional feet of masonry approaches. The entrance to one of these tunnels is shown in Pl. CXL.

The idea of constructing a storage reservoir at the site of the Cuyamaca dam and of bringing the water to supply the future city of San Diego was conceived by Mr. T. S. Van Dyke, who, with the advice of Mr. William E. Robinson as engineer, investigated the ground and surveyed the project between 1881 and 1886. In this latter year the San Diego Flume Company was organized and incorporated. The capital stock was fixed at $1,000,000, construction was begun in 1887, and the work pushed to a speedy completion.

The water supply as yet provided for is insufficient. The catchment basin of the San Diego river above the diverting weir is 105 square miles, while Sand creek adds 5 and the South Fork of the San Diego river 40 miles of catchment basin to the flume, giving the latter a total of 150 square miles. The mean rainfall of the year on this catchment basin is more than sufficient to provide an abundant perennial discharge, but it is so irregularly distributed that the discharge during the irrigating season is relatively small. The catchment area of Cuyamaca reservoir is 11 square miles, and according to observations made in 1,887 the total inflow that year was 2,980 acre-feet. The loss by evaporation amounted to 1,470 acre-feet, leaving 1,510 acre-feet available for purposes of irrigation. An additional loss is sustained from absorption by the passage of this water down Boulder creek to the head of the diverting flume and thence to the irrigable lands, so that the actual amount available for purposes of irrigation is comparatively small. That more storage capacity is required is clearly shown by the fact that in ordinary years there is only a supply sufficient to enable the flume to carry about 20 second-feet during the irrigating season, and that of the 150 square miles in the catchment basin only 11 miles are tributary to storage reservoirs. The plans of the company, however, contemplate the diversion of the headwaters of the Tia Juana river on the south and the San Dieguito on the north into the head of the flume and the construction of additional storage reservoirs.

The irrigable lands commanded by the works of this company embrace the entire valley of the San Diego river, including El Cajon, the high mesas between the river and Sweetwater creek on the south, and the Linda Vista mesa north of San Diego, an aggregate area of nearly 100,000 acres. The flume line proper commands the whole of El Cajon and a portion of the upper Sweetwater valley, while the pipe lines command the mesa east of the city of San Diego. All of this land is excellently situated for irrigation and is well adapted to the production of all the semi-tropic and citrus fruit crops, the yield from which in this region is large and profitable.

Cuyamaca reservoir has a surface area of about 1,000 acres and a maximum available capacity of about 11,500 acre-feet. Though its catchment basin is but 11 square miles in area, the average annual precipitation on this is about 45 inches, nearly sufficient in ordinary seasons to fill it. This reservoir is closed by an earth dam 635 feet long on top, 40 feet in maximum height, and 35 feet wide on the crest. It is 115 feet in width at its base and the maximum depth of the water which it will hold above the outlet sluices is 35 feet. The water slope of the dam is 1 on 2 and the downstream slope 1 on 1½, while the upper slope is covered with a riprap of stone 2 feet in thickness. The dam rests on a foundation bed of clay over 12 feet in depth, into which a trench 8 feet in depth is excavated, filled with puddle composed of one part broken stone, one part sand, and three parts clay, the whole well rammed. This is carried up as a puddle wall through the entire height of the dam, having a top width of 6 feet and a batter on both faces of 4 on 1. The clay bed on which this dam rests was accidentally developed when sinking test pits, as it was supposed that the foundation was granite and the original intention was to build a masonry dam. The surface of the ground under the inner slope of the dam was stripped and covered 2 feet in depth with clay puddle well bonded and the dam itself was built up of the hard clay which was found in excavating the foundation. A little beyond the south end of the dam is constructed a wasteweir, the sill of which is 5 feet below the crest of the dam, while its width is 50 feet and the slopes such that the velocity of the water flowing through it is 5 feet per second. This wasteweir is ample to discharge the greatest flood which may occur above the reservoir.

The chief element of weakness in this structure is the discharge sluice, consisting of a trench filled with puddle in which 18 inches of concrete is laid and above which the masonry culvert is built. This culvert is 3½ feet wide by 4½ feet high inside and 120 feet long, its bottom being placed at a level with the original surface, while it is given a fall of 3½ feet in its length. Owing to the defective bondage between the masonry culvert and the surrounding material of the dam a considerable leakage occurred at first. This has been recently diminished, however, by the addition of rings to the outer circumference of the culvert to prevent the creep of the water and by the adoption of other remedial measures. The water is admitted to the culvert by means of a circular brick tower 5 feet in diameter inside, and rising to a level with the top of the dam. This tower is provided with two wooden gates, closing openings 3 feet wide by 4½ feet high, the lower of these being at the bottom of the tower and the second 15 feet 9 inches higher. These gates slide vertically in wooden grooves, operated by chains from above. An iron gate is employed inside the tower to close the head of the outlet culvert.

After flowing down Boulder creek and the San Diego river for 12½ miles the water is diverted to the flume by means of a great pick-up weir built of uncoursed rubble masonry and extending entirely across the San Diego river. This weir (Pl. CXXV) is built in two tangents, the exterior angle of which points upstream. Near its south end (Fig. 91) and extending out for a distance of 108 feet to the head or regulating gates which admit the water to the flume, the cross section of this weir is 4 feet wide on top, or 1 foot less than that of the remainder of the weir. At a distance of 32 feet beyond the flume head is an open wasteway 20 feet wide, the crest of which is 4 feet lower than that of the remainder of the weir. For 14 feet beyond this wasteway the weir is again given its usual height as far as another wasteway, 165 feet in length, the crest of which is, like that of the first described, 4 feet lower than that of the remainder of the weir. The remaining 15 feet in length of the weir is again of full height. Between the two wasteways just described, and in the bottom of that portion of the weir which is built to the maximum height, also under the regulating gates at the head of the flume, are two single undersluices opened by means of gates which slide vertically and are operated by means of a screw and hand lever from above. One of these undersluices has its sill 14 feet and the other 18 feet below the crest of the dam.

The cross section of the weir (Fig. 91) is peculiar. It consists of two walls, the first as originally built being 34·5 feet in height, 5 feet wide on the crest and 16 feet wide on the base. It has an upstream batter of 1½ in 20, the lower batter being 7 in 20 and sunk to a depth of from 15 to 25 feet into the gravel of the river bed, presumably to bedrock. The second is a subwall on the upstream side across the deepest part of the channel and is 16 feet in height.

The regulator at the head of the flume consists of two gates, the sills of which are about 9 feet below the crest of the weir or 4 feet below the crest of the wasteway. These gates are 40 inches in the clear and are raised by a screw and hand lever from above. The flume which transports the water to the irrigable lands in the neighborhood of San Diego is built entirely of wood, everywhere laid in excavation or on trestles and in no place resting on embankment (Pl. CXXXVI). All fills are made with loose rock carefully laid and the excavated bench on which the flume rests is 12 feet wide, or 6 feet wider than the flume, thus giving a place on which the loose rock or stones which may slide from the hillsides above can lodge without injury to the structure. The flume (Fig. 113) is 6 feet wide in the clear with plank sides 16 inches in height, though the frame posts are 4 feet in height, so that whenever the demand for water requires it and the supply warrants additional planking may be added until the depth of the flume is increased to 4 feet. The bottom and sides are planked with 2-inch redwood planking. At a point 200 yards below the head gates is constructed an escape or wasteway 4 feet wide which discharges into a short flume 50 feet in length by which the waste water is led back into the San Diego river. The grade of the flumes is $4\frac{3}{4}$ feet per mile, its maximum capacity 50 second-feet, and its total length 34·85 miles. Its present average capacity, however, is but about 18 to 20 second-feet. In all there were consumed in constructing the flume and trestles 8,840,000 feet of lumber.

The tunnels on the line of the flume have inside dimensions of 6 feet wide by 6 feet 1 inch high in the clear. In loose material the sides are lined with masonry 12 inches in thickness to a height of 4 feet, on the top of which rests 6 by 8 inch timber backed by 3-inch lagging. In rock the sides are finished smoothly with plastering. (Pl. CXL.)

A distributing system consisting of pipes has been laid from the end of the flume to the top of the mesa overlooking San Diego, a distance of 9 miles. Branch pipe lines have been constructed to deliver the water to the various irrigated lands. In all this work cost—

For engineering and superintendence	$54, 800
For tunneling, grading and ditches	487, 000
For flumes	47, 000
For Cuyamaca reservoir	51, 000
Cost of land for reservoir sites, etc	100, 000
Total cost, including miscellaneous items, interest account, etc., to end of 1888	958, 790

MERCED RESERVOIR.

This reservoir, with its auxiliary canals and distributive system, is the property of the Crocker-Huffman Land and Water Company. The system consists of a temporary diversion weir on the Merced river, about 25 miles above the city of Merced, California, of a canal 27 miles in length which leads the water from the river to the reservoir, of the storage reservoir situated about 5 miles northeast of Merced, and of the distributing canals and pipe lines which convey the water to the town and to the irrigable lands.

Originally there existed at the site of the present canal a small ditch known as the Farmers' canal, which tapped the Merced river about 4 miles above Snelling and irrigated several thousand acres on the south side of the stream. In 1882 the present company decided to build a new and larger canal on the site of the old one, and in 1883 operations were commenced with this end in view, the canal heading as did the

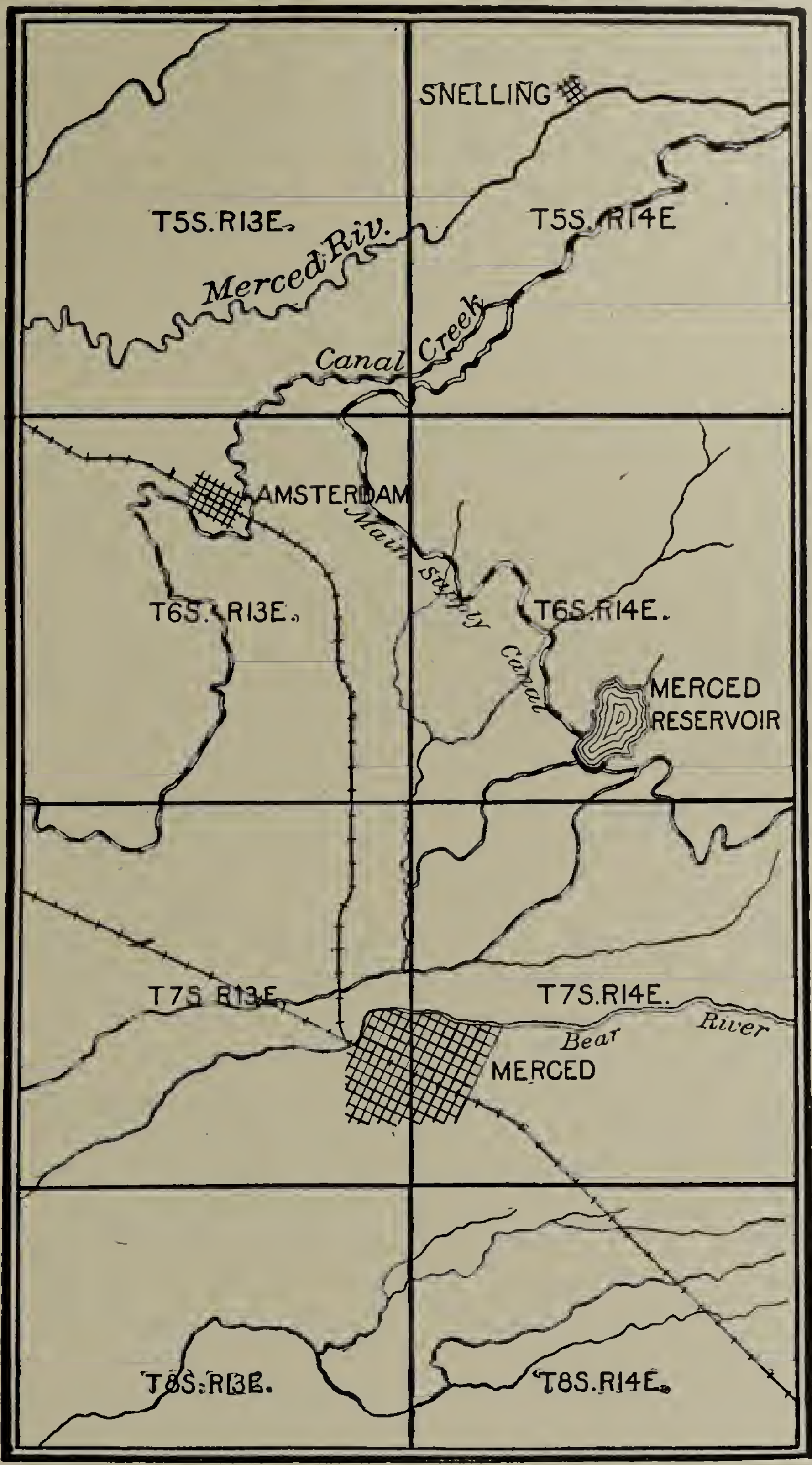


FIG. 128.—Merced reservoir system.

previous one a short distance above Snelling and skirting the river bluffs until the mesa was reached, after which it is brought to the Merced reservoir into which it empties.

The catchment basin of the Merced river at Snelling has an area of 1,076 square miles and its mean annual discharge averages between 1,200 and 2,500 second-feet, while its discharge during the irrigating season in the late spring and early summer is highest, ranging between 1,500 and 4,000 second feet. Its maximum recorded discharge occurred in June, 1884, and amounted to 6,510 second-feet. The lands commanded by the Crocker-Huffman canal system are situated immediately south of the Merced river in the neighborhood of Merced and consist of about 150,000 acres, most of which is well adapted to the cultivation of vegetables and of such temperate zone fruits as grapes, prunes, apricots, peaches, etc.

The Merced reservoir (Fig. 128) has a surface area of 500 acres and is closed by a dam 4,000 feet in length and 54 feet in maximum height, the top width of which is 20 feet and the capacity 15,000 acre-feet. The available capacity for purposes of irrigation, however, is somewhat less. The loss from evaporation is rather large, being between 5 and 6 feet per annum, and with the additional loss by percolation it has been found that the total loss from absorption during the three hottest months in the year amounts to about 6 feet, while the losses during the remainder of the year are about counterbalanced by the receipts from rain and surface drainage. The dam is quite high for nearly 2,600 feet of its length, the remaining 1,400 feet being a mere embankment of earth not over 10 feet in height. It is constructed of earth, its inside slope being 1 on 3 and the outer slope 1 on 2, while the inner slope is riprapped with a depth of 12 inches of stones extending for a distance of 15 feet below the crest of the dam. The base of this embankment at the deepest point is 275 feet in width. This dam was constructed by Mr. C. D. Martin, chief engineer, and is composed of a sandy clay laid dry in layers and well tramped over with scrapers. Water was so difficult to obtain during its construction that no attempt was made at puddling the dam or constructing a puddle wall through it. It has been built up with such care, however, that though it has stood for 6 years it shows no signs of weakening. The foundation is of the same material as the mass of the dam and test borings showed its depth to be at least 50 feet. The foundation was built down through a surface layer of 3 feet of hardpan, and below this was found the sandy clay bed on which the dam rests.

The catchment area of the reservoir proper is so small that it was not considered necessary to provide any other escape than the outlet of the reservoir which has a capacity of about 100 second-feet. About a mile above the reservoir on the main supply canal is an escape discharging into a narrow watercourse and at an elevation 1 foot above the canal sill at the point where it discharges into the lake, so that if the lake were exceptionally high, this escape would be brought into operation. The discharge pipe is 2 feet in diameter and is constructed of one-half inch cast iron laid in a brick tunnel 4 feet in diameter, the walls of which are 1 foot in thickness. Every 15 feet apart on the outer circumference of the tunnel are rings of masonry 1 foot in thickness and projecting 2 feet above the outer surface of the tunnel, the object of which is to prevent the travel of seepage water. In addition to this outlet pipe, which carries water under pressure to the city and to some of the surrounding irrigable properties there is at the south end of the dam an ordinary discharge gate placed a few feet below the maximum surface level of the reservoir. This admits the water to the main distributing canal which commands the larger portion of the irrigable lands.

The head works of the feeder canal on the Merced river are of the simplest and crudest description, consisting of an old weir built of brush, rocks and crib work, the total length of which is 250 feet and the height 21 feet. The canal heads 200 feet above the dam at a slight angle pointing upstream and its entrance is closed by a set of sixteen regulating gates, each 5 feet wide in the clear and 20 feet in height above the canal bed. This regulator, which is formed somewhat like a long flume with gates in it, has a floor of 3-inch planking extending 20 feet upstream and 10 feet downstream. Anchor and sheet piling is let 4 feet into the rock and cemented under the upper and lower ends of the floor and under the gates, the latter being simple wooden structures lifted by means of a hand lever operated from above.

The first portion of the main canal, which is 7 miles in length, has a capacity of 1,500 second-feet, and a bed width of 60 feet, with slopes of 1 on 2 inside, and 1 on 1½ outside, a depth of 8 feet of water and a grade of 1 foot per mile. This is excavated mostly in sand and gravel, while the remainder of the canal is generally in fairly good soil. On the line of the canal are two tunnels, the first 1,700 and the second 2,000 feet in length, each 20 feet wide at the bottom and 14 feet high to the summit of the arch, with a grade of 10½ feet per mile. The first tunnel is excavated entirely in sandstone and requires no lining, while the second is in friable sandstone or gravel, and is timbered throughout. Below the first tunnel is taken off the first main distributary which discharges into a creek, the line of which is utilized as a canal. The practice of utilizing stream beds as distributary channels is employed generally on this canal, but is not one that is to be commended.

Below this first distributary the canal is diminished to a bed width of 50 feet, a depth of 9 feet, while the depth of water is 7 feet and the slopes and grade are the same as before. A short distance below the canal head at Snelling a main branch is designed which shall skirt the foothills well above the supply canal and reservoir so as to command a large acreage of excellent land. This will empty its waters into Bear creek, which is used as a distributary channel, while the distributary canal leading from the reservoir likewise empties into Bear creek, though a portion of its water is carried across and beyond that creek to command lands further down.

It was difficult to ascertain the exact cost of this work, but approximately the first cost of the entire system, including canals, distributaries, reservoirs, etc., amounted to about $1,500,000, of which the reservoir proper cost about $400,000. Since its completion, however, maintenance charges have amounted to about $20,000 per annum. It seems that these figures are excessively high, but the $1,100,000 put down as the cost of the canals really includes the cost of most of the lands owned by the company, amounting in all to about 60,000 acres. Of the total area commanded by this canal about 75,000 acres are irrigable lands of the best quality. Water rights are sold by the company at $10 per acre and in addition $1 per annum per acre water rental is charged. The company sells its lands with a water right in perpetuity at from $100 to $200 per acre, according to their location.

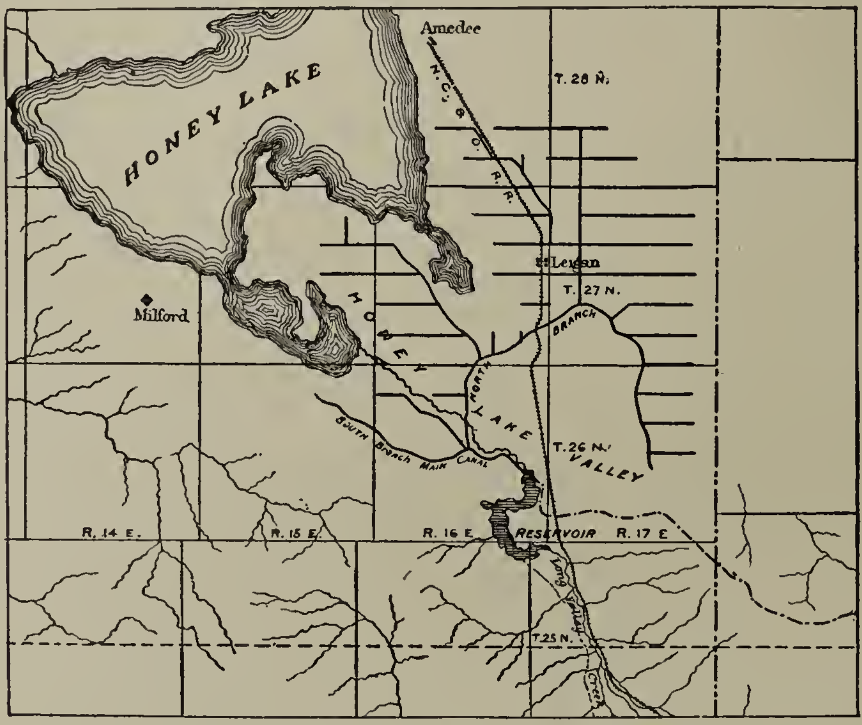


FIG. 129.—Honey lake valley reservoir system.

LONG VALLEY RESERVOIR.

There has recently been projected a very promising water storage project in Honey valley, in northern California. The reservoir site and lands are the property of the Honey Lake Valley Land and Water Storage Company, which has had detailed surveys and estimates of the project made under the direction of Mr. L. H. Taylor, chief engineer. The project includes the construction of a storage reservoir closed by an earth dam 96 feet in maximum height and 950 feet in length. This dam is situated on Long Valley creek at the foot of Long valley at an elevation of 4,140 feet. From this the main canal is diverted to the left bank of Long Valley creek, which it follows for about 2½ miles, where it is divided into two main branches, the southern branch skirting the foothills and commanding a small area of land between them and Honey lake and Long Valley creek to the north, and having a length of about 7 miles; the north and main branch, the larger of the two, crossing Long Valley creek and commanding a majority of the irrigable lands in Honey Lake valley, the total length of this main line being about 14 miles (Fig. 129).

Long Valley creek, which is the source of water supply, has a catchment area of about 420 square miles lying just to the east of the Sierra Nevada range and draining a watershed ranging from 4,000 to 9,000 feet in elevation. This stream is intermittent, discharging large flood volumes during short periods of the winter season, and almost entirely disappearing during most of the summer and fall. Its catchment basin is very precipitous, thus insuring a large percentage of runoff, and the precipitation, as nearly as can be ascertained, ranges between 25 and 40 inches per annum. During the occasional floods in the fall the stream discharges several thousand second-feet, while in March and April it discharges regularly from 100 to 300 second-feet, increasing to several thousand at exceptional floods. From this it will be seen that the water supply for the reservoir is ample, since the total estimated discharge from the drainage basin rarely falls below 60,000 acre-feet. The irrigable lands which will be commanded by this reservoir are of most excellent quality, the soil being a dark sandy loam of considerable depth and having a good slope for drainage. This land is favorable, as is the climate, for the production of the temperate zone fruits and all kinds of vegetables and forage plants.

The dam is situated at the mouth of the creek where it leaves Long valley and enters Honey lake valley. The canyon at this point has a bottom width of about 200 feet and is from 50 to 100 feet in depth, the stream flowing between rather precipitous walls. Above this dam site the canyon widens until it has an average width of from a quarter to a half mile for several miles. Its slope is so gradual that a dam 90 feet in height will back the water for about 6 miles. The material of which the sides of the canyon are formed and on which the dam will be founded consist of a series of strata of fine clay, cement, and sand overlying a soft, bluish shale. These strata dip in such a direction as to have the effect of preventing leakage in the bed of the reservoir. Borings show an impervious clay at a depth of about from 3 to 6 feet on which the dam can be safely constructed.

The surface area of the reservoir will be 1,080 acres and its capacity 32,910 acre-feet. The dam (Fig. 130) will be 96 feet in height from its base to its crest, 500 feet in width at the base, 20 feet in width on top, and 950 feet in length on its crest. Its upper slope will be 1 on 3, faced with a sufficient thickness of stone paving to protect it against wave action, while its lower slope will be 1 on 2. It is proposed to build a puddle wall through the center of this dam, having a base width of 30 feet, a top width of 10 feet, and rising 2 feet above high-water mark.

An ample wasteway will be provided at the west end of the dam. This wasteway will be excavated in the clayey material forming the abutment of the dam and will discharge back into the creek a few hundred feet below the toe of the structure. Its sill will be at an elevation of 10 feet below that of the crest of the dam and its total length will be 140 feet, divided into twenty openings of 6 feet each. The discharge capacity of this wasteway is estimated to be sufficient to pass the largest flood likely to occur on the catchment basin of this stream. The outlet sluice will be situated west of the creek at an elevation of 25 feet above its bed. It will consist of a trench in the side of a hill in which an ample thickness of puddle will be laid. Resting on this puddle will be an arched conduit 5 feet in maximum height and about 6 feet in width. This conduit will be laid on a grade of 1 in 500 and at uniform distances on its outer rim will be placed rings of masonry to stop the travel of water along its surface. The conduit will be covered with puddle to a height equal to the surface level of the ground and will be closed near its upper entrance by a valve operated from a gate tower.

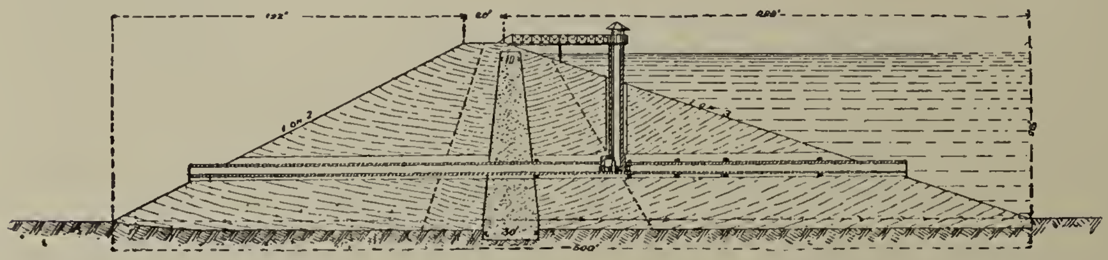


FIG. 130.—Honey lake dam, cross section.

As before stated the main channel will be 2½ miles in length and the south and north main branches, respectively, 7 and 14 miles in length. The first 2½ miles of main canals will be in sidehill cutting in favorable material, while the remainder of the work will be in level excavation. In addition to this there will be 28 miles of main branchs and about 57 miles of distributary canals so laid out as to deliver water to every half-section of land. On the line of the north main canal will be a flume 1,000 feet in length crossing Long Valley creek. Owing to the steepness of the surface slope a fall will be required on the north main line just below the bifurcation, while several falls will be required in various parts of the distributing system. The capacity of the main canal will be 180 second-feet. It will have a bottom width of 10 feet and will carry a depth of 4½ feet of water. The north and south main canals will begin with bed-widths of about 10 feet and will carry a depth of 3 feet of water. The north main will have a capacity of 170 second-feet at its head, while the capacity of the south main will be but 40 second-feet. These works are estimated to cost in all $101,000, distributed as follows: Construction of dam, $57,000; outlet works of masonry, waste gate, etc., $7,000; main canals, $12,000; branches, flumes, etc., $10,000; and incidentals which bring the total up to $101,000.

WALNUT GROVE RESERVOIR.

One of the most appalling catastrophes that has occurred in this country as the result of the breaking of a reservoir dam was the giving away of the Walnut Grove dam on the Hassayampa river in Arizona on February 22, 1890. While, as proven by the result, this dam was badly built, its destruction was largely due rather to the insufficiency of wasteway and carelessness in the workmanship than to any fault in the original design. A description of this dam is deemed desirable, as it represents a type of structure which is rapidly becoming popular in the Far West, and numerous examples of which were constructed in the hydraulic mining region of California in earlier days. The design of the Walnut Grove dam is an improvement on several structures of the kind which have existed for the last quarter of a century, and have during that time withstood numerous floods and freshets. This type is known as the rock filled dam, and is essentially a product of Western engineering.

Walnut Grove is a valley situated about 30 miles south of Prescott, and through it runs the Hassayampa river, one of the longest streams in the territory. The Walnut Grove region contains several million acres of excellent tillable soil, which, until recently, were uncultivated, with the exception of a few scattered ranches where cereals and hay were raised. Recent experience with irrigation has shown that the soil and climate are capable of producing excellent crops of grapes and temperate zone fruits, and the more valuable vegetables and grains. A company for the construction of the Walnut Grove dam was organized in 1886 and work was commenced immediately thereafter. The dam is situated at the lower end of the open valley of Walnut Grove, where the stream enters the canyon of granite rocks. The object of the storage reservoir formed by the dam was both for the mining of gravels in the bed of the Hassayampa river and for irrigating the lands in the valley below the reservoir.

The elevation of the Walnut Grove dam is about 3,500 feet above the sea level; the drainage area above the dam is variously estimated at from 260 to 390 square miles. No accurate survey has as yet been made of the region. The annual rainfall of the catchment basin is supposed to average about 16 inches. The country rock at the dam site is a coarse granite, easily quarried, and the high price of lumber and cement and other supplies determined the method of construction.

Prof. W. P. Blake, of New Haven, was the first chief engineer, and it was he who originally designed the dam and under whose supervision its construction was commenced. The foundation wall was carried across the stream to bed rock through about 20 feet of sand and gravel under the direction of Prof. Blake. Col. E. N. Robinson, of San Francisco, who succeeded Prof. Blake as chief engineer, had constructed several dams of the same kind in California which have successfully withstood the floods of a quarter of a century. Under Col. Robinson the dam was recommenced in the rear of Prof. Blake's foundation wall. It consists of front and back walls 14 feet thick at the base and 4 feet thick at the top, with a loose rock filling between, the whole made water-tight by a wooden sheathing. Mr. Robinson designed a wasteway 55 feet wide and 12 deep cut through a ridge one-half mile north of the dam and spilling into a separate watercourse, which would in all probability have carried off the great flood of 1890. For some unaccountable reason a much smaller wasteway was ultimately constructed.

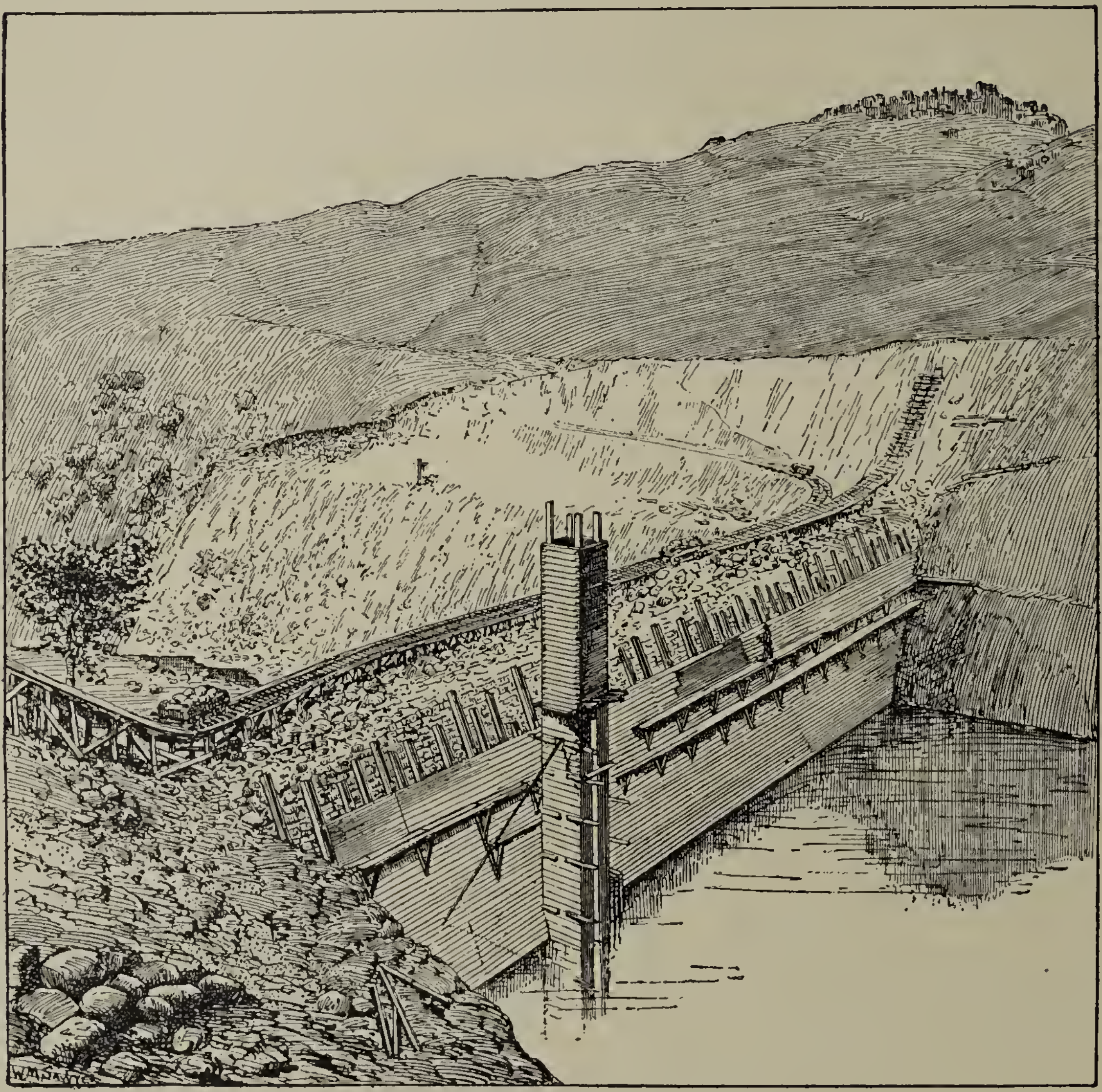


FIG. 131.—View of Walnut Grove dam.

The side walls of the dam consisted of rough blocks of granite, laid without mortar or cement, and the water face was planked with two thicknesses of yellow pine plank, 3 by 8 inches, spiked to pine timbers laid horizontally in the rubble wall as it was built up; tarred paper was laid between the two courses of plank. The outer face of this sheathing was finally calked, the outer layer of planks breaking joints with the inner layer, and the outer surface of the whole covered with paraffin paint. The dam (Fig. 131) was 420 feet long on top, 138 feet thick at bottom, about 15 feet thick at top and 110 feet in greatest height at center. It contained between 45,000 and 50,000 cubic feet of rock. The area of water surface of the reservoir was about a thousand acres and the maximum available depth of water was nearly 105 feet. It is difficult to discover what was the exact capacity of this reservoir,

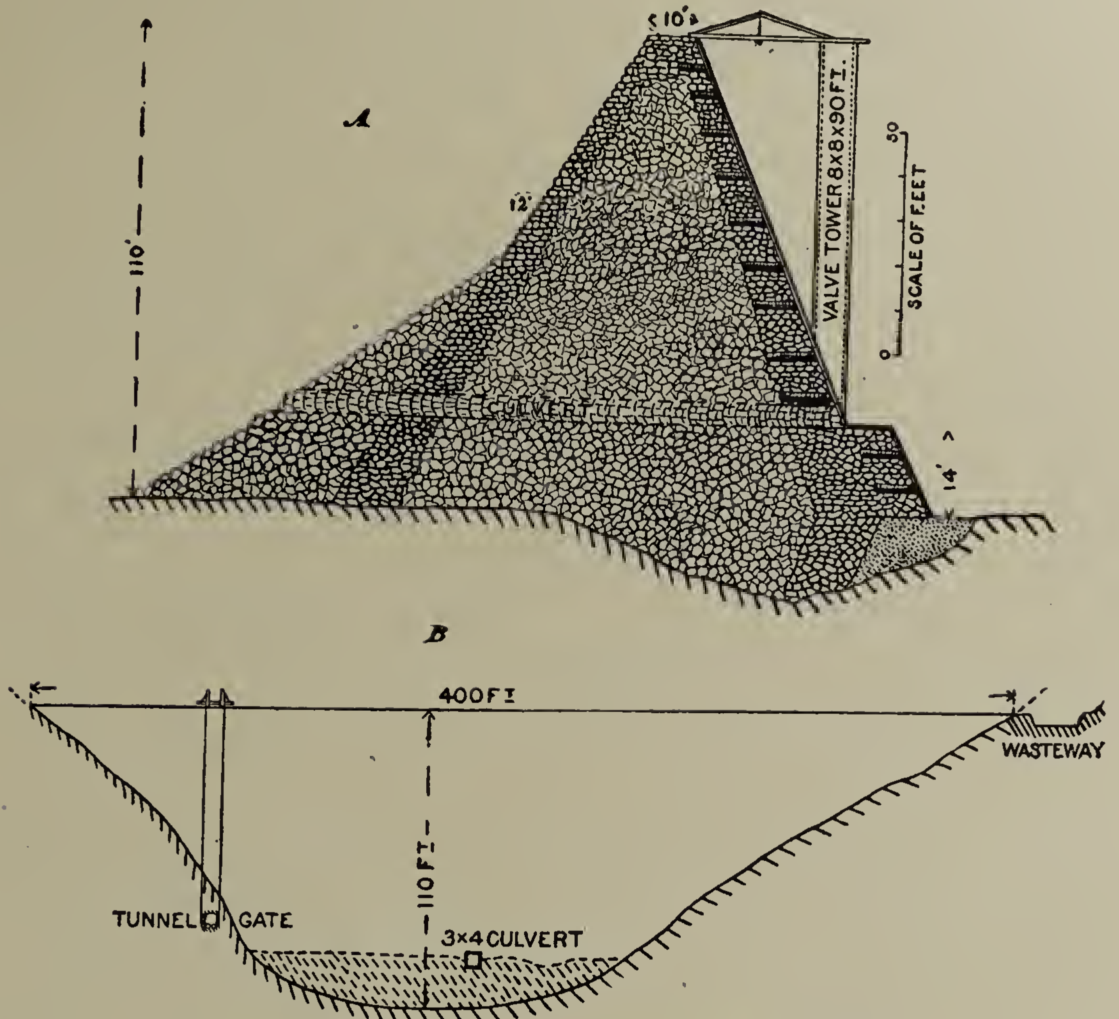


FIG. 132.—Walnut Grove dam. Cross section and elevation.

but it is believed to have been about 7,000 acre-feet, though one estimate places it as high as 14,000 acre-feet. This latter figure is doubtless too great. The upper slope of the dam is given as 2¼ on 1 and the lower slope 1½ on 1. This was, however, increased for the lower half of the dam to about 1 on 1 by the addition of a pile of loose rock after the completion of the structure. The wasteway as built was 26 feet wide and 7 feet in depth and was constructed at one end of the dam, the spill falling near or against its toe. The slope of this wasteway was 5 feet in 100, and at its terminus was a steep drop to the river bed below.

One of the much discussed points in connection with the construction of this dam was its foundation; it was intended that it should be founded on bed rock. Witnesses before the courts, men who had taken part in its construction, claimed that the foundation did not reach bed rock on the upstream face, as shown in Fig. 132. The body of the loose rock rested on the gravel bed of the river. The lower wall rested on bed rock, but a portion of the upper wall rested only on river gravels. This fact was discovered during the construction of the dam. An excavation was made under the dam and a masonry wall 14 feet deep and about 14 feet wide was let down, presumably to bed rock, with another portion of this wall turning inward to rest on bed rock. It was claimed, however, that this wall did not come within 5 feet of bed rock, so that in fact even after the alterations the dam still rested on the gravels. The main upstream wall of the dam rested for only 2½ feet on this secondary base which was built under it, the remainder of the thickness of the wall resting on the buttress which inclined inward to bed rock. The correctness of this view of the construction of the dam is indicated by the fact that considerable water passed under or through the dam in spite of its plank sheathing.

In constructing the dam (Fig. 131) quarries were opened upon both banks of the stream above the top of the dam, the stone was loaded upon cars and was lowered on the dam by a bull wheel and brake. A three-rail railroad was laid upon a trestle across the dam, its height being from 10 to 15 feet. These loaded cars were dumped into the center of the dam, forming the loose rock filling, and the legs of the trestle were left in the wall, only the caps and stringers being removed during the first stages of construction. Derricks were used to distribute the larger stones; later on the center was kept high and the stones for the wall were moved by bars. The effect of this upon the stability of the dam was bad, as the stones tended to form a convexly curved bed whose slopes made acute angles with the direction of the resultant pressure. The manner of leaving the stones loosely piled in the center of the dam with large timbers mixed in with them doubtless permitted considerable settlement as the high floods topped the dam and thus produced a strong outward thrust to rupture the loosely laid, uncemented confining walls. In the construction of the wooden sheathing, juniper logs from 8 to 10 inches in diameter and about 6 feet long were built into the wall upon the upper face, as before described, and projected from its surface about 1 foot; vertical stringers about 6 by 10 inches, of varying size, were bolted to the logs, the stringers being about 4 feet apart. At the joints of the stringers logs were built into the wall about 2 inches above the top of the stringer and two 4x10 spliced pieces were built to the logs and spiked to the stringers by galvanic bolt spikes, thus completing the joint. Upon the main wall of the dam and over these stringers the double planking before described was laid. The junction of the plank skin and the bed rock was secured by Portland cement.[1]

Through the dam was a culvert 3 by 4 feet inside, at about the level of the old creek channel. This was boarded with 3-inch planking inside and had a gate to draw off water and wastage. The water for use was taken into an inlet tower which was built of 8 by 8 inch timbers 8 feet long. There were two inlet valves, one at the base of the tower and one 20 feet higher. These were of wood, sliding upon wood, and each had a superficial area of 15 square feet. A 6-inch-square wooden stem ran up on the outside of the tower to a platform where the mechanism was placed to open and close the valves. Two men could give a pull on this valve stem of about 500 pounds and with a 30,000-pound pressure could not move the valve, as the load to be overcome was over 11,000 pounds. From the valve tower the water was conveyed in two 20-inch iron pipes to a house below the dam, where each pipe was provided with a gate. The pipe went through a tunnel made of rubble; part of the way through a spur and arched the remainder of the way. With 70 feet of water above the bed rock the dam leaked nearly 3 second-feet.

The destruction of the dam is assigned by various interested parties to different causes. It has been questioned in the courts and elsewhere whether the dam actually did leak and whether its construction was faulty. A short description of the dam by Prof. Blake[2] may throw some additional light on the subject:

> The reservoir was filled by the first floods and the water rose rapidly to and beyond the 80-foot contour line. As to the effect upon the stream below there has been an agreeable surprise either from a partial opening of one of the gates or a leak. There has been a constant flow of water from the dam and this has kept a constant stream through the valley, giving more water than usual along its course, so that instead of the owners of water privileges denouncing the dam and asking for injunctions they are hoping the dam will always leak to their advantage. These results are of great value as to the demonstration of what the functions of such dams and reservoirs may be throughout the arid regions of the west; even if not perfectly tight they would be of immense value in catching the temporary floods and in equalizing the flow of such intermittent streams as the Hassayampa and many others. As an illustration of the importance of more than one large reservoir on the same stream an experience below the Walnut Grove dam last summer may be cited. A heavy rainstorm and shower, "a cloud burst," swept over the mountains below the dam and suddenly flooded the canyon to such an extent that ditches and waterwheels were swept away.

Prof. Blake here plainly acknowledges the presence of a leak, and congratulates the people of the valley upon it. He also attracts attention to occasional cloud-bursts as a possible source of additional water for purposes of storage below the main dam. It apparently never occurred to him that such a cloud-burst might break above the dam, and owing to the insufficiency of its waste way and the imperfect method of operating the outlet sluices destroy it, as it did.

---

[1] Luther Wagoner, Walnut Grove dam. Transactions Technical Society of the Pacific Coast, vol. v, 1888.

[2] William P. Blake, Notes upon some results of the storage of water in Arizona. Trans. Am. Inst. of Min. Eng., Feb., 1889, New York.

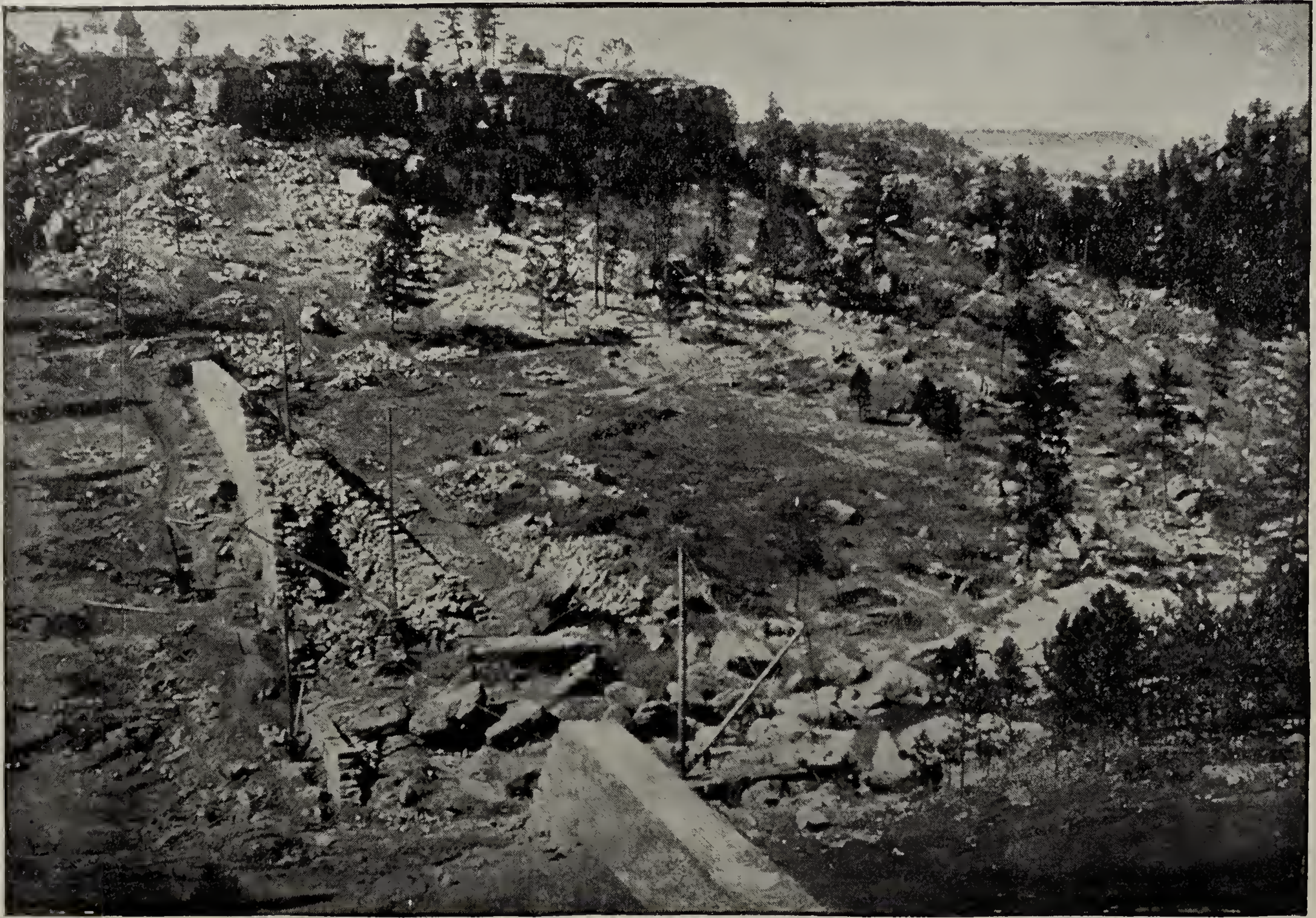
To prevent high waves from splashing over the dam a 2-inch plank was carried half way across the top of the dam. In the great flood which ruptured this structure the water flowed uniformly over its crest to a depth of 3 feet. The only eyewitness to its destruction claims that the dam collapsed and fell into the reservoir, thus indicating that it was undermined where it did not rest on bed rock, and that its destruction was not entirely due to its being topped by the waves. One engineer, who had watched the construction of the dam and who was acquainted with the circumstances attending its construction and destruction, says that he believes the dam to have been destroyed by undermining and by a settling of the interior rock filling, leaving a dry rubble shell.

CASTLEWOOD RESERVOIR.

A very interesting composite irrigation scheme, combining as it does two different systems of water storage, is the project of the Denver Water Storage Company. The system comprises a main storage reservoir known as Castlewood lake, situated on Cherry creek, Colorado, at a narrow point in the canyon and about 30 miles southeast of the city of Denver; of a diversion weir a mile and a half lower down on Cherry creek, which diverts the water that has been turned into Cherry creek from the reservoir and passes it into the Arapahoe canal which heads at the weir; of the main line of the Arapahoe canal which conveys the water to the irrigable tract situated immediately southeast of Denver and west of Cherry creek; and of a series of four secondary reservoirs situated in different portions of the irrigable lands in natural depressions in the surface. This system of secondary reservoirs will be filled by water brought down by the canal when not wanted for the irrigation of the land or when a superabundant flow in Cherry creek would otherwise be wasted. The area of good irrigable land commanded by this system as at present constructed is 30,000 acres.

Cherry creek above the reservoir site has a catchment area of about 200 square miles, the available run off of which is estimated to average about 2,300 acre-feet per annum, while the maximum flood anticipated is about 7,000 second-feet. In ordinary seasons Cherry creek sinks to a mere rill, discharging a few second-feet, but it is hoped that in average seasons the flood discharges will fill the reservoir. The dam site is located at a point where Cherry creek flows through a rather narrow gorge between the rock bluffs and above and behind which is a broad flat which will afford an abundant storage space. The reservoir has a surface area of about 200 acres and a capacity of about 5,300 acre-feet.

The design of the dam which closes this reservoir is peculiar, and



VIEW OF CASTLEWOOD DAM.

has been severely criticised by the people living below it, and by the inhabitants of Denver, who consider it unsafe. It is founded on a bed of clay and bowlders from 7 to 30 feet in depth, and is composed of an outer shell or wall of large blocks of coursed rubble masonry, the thickness of which on the upstream face is about 6 feet on top and 12 feet on the bottom (Fig. 133). On the downstream face the wall is from 5 to 7 feet in thickness, this face being laid in steps the height of which vary from 1½ to 2½ feet. The main body or center of the dam consists of loose rock inclosed between these walls. The maximum height of the dam is 63½ feet; it is 586 feet in length on the crest, and 100 feet of this length is lowered 4 feet in order to form a wasteway over which flood waters may be discharged. In addition to this wasteway there is another around one end of the dam which is 40 feet wide and has a fall of 4 feet in its length of 400 feet, discharging back into Cherry creek below the dam, over a masonry-lined channel. The upper 4 feet of the dam is vertical on both sides, is 8 feet in width, and is constructed of rubble masonry. The outer slope of the remainder of the weir is 1 on 1, while the inner slope is 10 on 1. The mode of constructing this work and its general character are well shown in Pl. CXLI.

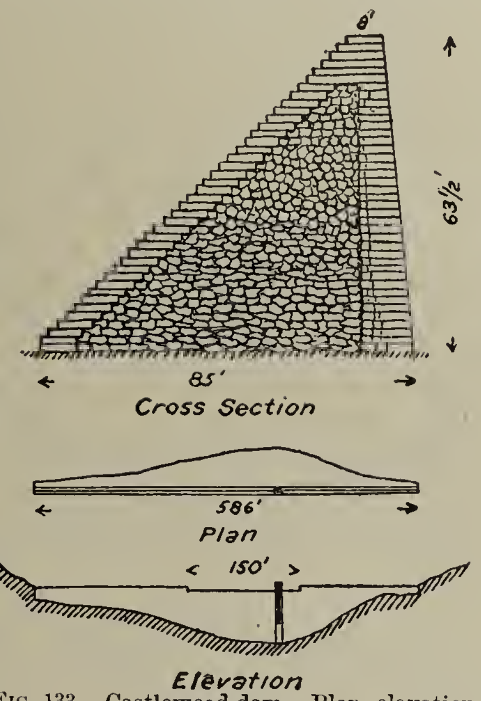


FIG. 133.—Castlewood dam. Plan, elevation and cross-section.

The well-shaft controlling the outlet sluice is of the best masonry, and is built in the dam close to its upper slope, the total thickness of the wall on both sides being 4 feet. Discharging into the shaft are four sets of iron intake pipes set in cement, each set consisting of two pipes. These are each 12 inches in diameter, the lower set being on a level with the bottom of the reservoir and the others each 6 feet apart vertically. These pipes discharge into a central well from which an outlet pipe 30 inches in diameter leads the water off. This pipe is surrounded by 4½ feet in thickness of concrete. The valves of the intake and outlet pipes are controlled from a valve chamber built into the body of the dam.

Shortly after the completion of this structure, and before it had quite filled with water, injunctions were brought by farmers and people living in Denver, below the reservoir, to prevent its being filled, as they considered it unsafe. An investigation was had, and at the instance of the courts plans were devised for the reinforcement of the dam. These consist chiefly in building above it a heavy earth embankment, and this work is now under construction and nearly completed.

After being discharged into Cherry creek the storage water flows down the bed of that stream for a distance of 1½ miles to a diversion weir which diverts it to the canal on the left bank. This weir is 150 feet long, 10 feet high, and with the exception of 54 feet of its length in which the head gates are situated, is composed of piling, sheeted on both faces and forming a rectangular wall which is filled with sand. Through the center of this portion of the weir is a waste way 60 feet in width, the crest of which is 3 feet lower than that of the remainder of the structure. The head gates are built in the last 54 feet of the weir, which is constructed of rubble masonry, a continuation of the pile boxing. These gates are three in number, their total height being 6 feet, and their width between centers 4 feet. The masonry section of the weir in which they are constructed is 3 feet wide on top, its inner slope being 1½ on 1, and the outer slope vertical.

The canal by which the water is led into the secondary reservoirs and to the irrigable lands has a total length of about 50 miles, including its main branches. The first 25 miles of this line is 12 feet wide on the bed, carries 3 feet in depth of water, has slopes of 1 on 1½, and a grade of 1½ feet per mile, giving a discharge capacity of 75 second-feet. In the next 10 miles the canal has a bed width of 10 feet, while the remaining 15 miles in length of the line has a bed width of 8 feet, the slopes and grade in each case remaining the same. The line of this canal is mostly constructed in an easily worked clayey loam and is entirely in excavation. It crosses numerous streams and ravines in the passage of which inverted siphons are used. In all there are 5,300 feet of wooden siphon pipe, the longest one being 1,800 feet in length with a maximum depression of 100 feet, under a water pressure of about 50 pounds to the square inch. In addition to these siphons there are 20 flumes on the line of the canal, the greatest of which is 200 feet long and 12 feet high. These flumes are utilized for the introduction of escape ways placed in their sides so that the flow of water in the canal may be controlled.

Of the secondary storage reservoirs one already constructed and in operation has a surface area of 60 acres and a capacity of 700 acre-feet. It is in a natural depression, the maximum depth of which is 16 feet, and is emptied by means of a wooden outlet pipe let into the embankment which closes the lower side of the basin. This earthen embankment is 10 feet in maximum height 12 feet wide on top, its inner slope being 1 on 3 and its outer slope 1 on 1½. As there is no catchment basin contiguous to this reservoir it has not been necessary to supply it with a wasteway, the outlet sluice being sufficient to insure its safety.

The Denver Land and Water Storage Company has a paid up capital of $2,500,000 and stock to the amount of $800,000 has been issued, a portion of which has been negotiated. Much of this money has been utilized in the purchase of land, and this is controlled by the company. The works have cost about $425,000, while a small additional amount is now being expended on repairs to the dam.

BEAR VALLEY RESERVOIR.

This reservoir forms a part of the property of the Bear Valley Irrigation Company and is situated in the San Bernardino mountains, a little east and north of San Bernardino, California. Originally it built the present or old Bear valley dam in order to store water for irrigating the lands in the neighborhood of San Bernardino and Redlands. These lands have shown such a remarkable development and the value of water for irrigation has increased so greatly during the past few years that the company has extended its scope and operations and is constructing a new and larger dam to replace the existing one, with a view to storing an additional amount of water and furnishing it to other irrigable lands. Among these the chief are the Alessandro and Perris irrigation districts south of San Bernardino, which already derive their water supply from this company. As will be seen, this company is not operating, as others usually do, with the intention of irrigating its own lands and supplying its own canals, but it stores and provides a water supply for

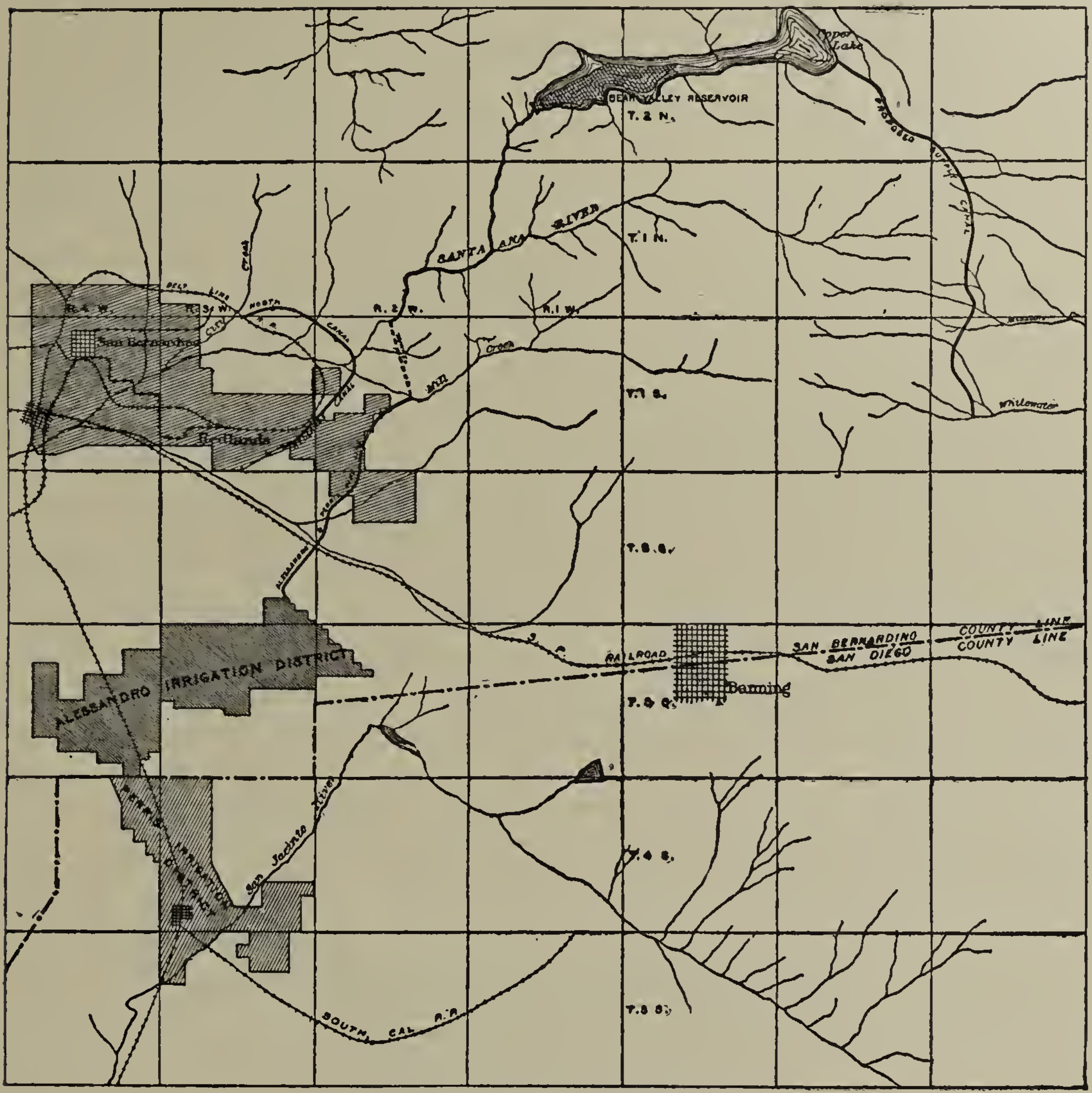


Fig. 134.—Bear valley reservoir system.

the use of the various irrigation companies and ditches in San Bernardino valley and the irrigation districts south of it.

Bear valley is a large flat mountain basin about 6,200 feet in altitude in the heart of the San Bernardino mountains. As will be seen from Fig. 134, this valley is practically on the summit of the mountains, and while the lower end of it drains through Bear creek, which joins the Santa Anna river above Redlands, its upper end is a sort of interior drainage basin separated by a very low divide from the drainage of the Mohave desert on the north. The drainage area tributary to this valley includes 77 square miles, of which about 45 square miles are tributary to the lower end of the valley in which is the old reservoir. The rainfall on this area is exceedingly heavy. According to observations made in the year 1883–'84 it amounted to 93·3 inches, the rainfall in the months of February and March being respectively 24 and 35 inches. This year was, however, one of more than ordinary rainfall and the annual average is presumably less than this. Great downpours occur frequently in this high mountain region. In February, 1890, a rainfall of 19 inches was measured at the dam site in twenty-four hours. It was estimated that the runoff of the catchment basin of this reservoir in the year 1883 amounted to 360,000 acre-feet.

The waters stored in the reservoir are turned back through the outlet sluice into Bear creek down which they flow for about 20 miles with a total fall of about 5,000 feet to the San Bernardino valley, at the head of which they are diverted for purposes of irrigation. This system commands an enormous area of the highest class of citrus fruit lands, including about 75,000 acres in San Bernardino valley, and as much more in the neighborhoods of Alessandro and Perris. Of this perhaps 40,000 acres between San Bernardino and Redlands are either under cultivation or are commanded by irrigation works, while 25,000 acres in the Alessandro district and 23,000 acres in the Perris district are guaranteed a water supply by the company.

The reservoir site now occupied was discovered by a party making surveys in 1880 under the direction of the state engineer of California. In May, 1883, it was visited by Mr. F. E. Brown, who made surveys of the project later and who has been intimately connected with all of the engineering and financial operations connected with its development since. The Bear Valley Land and Water Company was incorporated in September, 1883, with a capital stock of $360,000 divided into 3,600 shares of $100 each. Work was begun on the dam in the same month and continued when weather permitted until November, 1884, when it was completed. Various assessments were made on this stock until, in 1887, the holders had paid in $45 a share, and the share was valued at from $225 to $250.

The present dam is 64 feet in height and when filled to the highest flood limit, say 60 feet above the base, the water reaches 6 miles up the valley and has an average width of six-tenths of a mile, a surface area of 2,252 acres and a capacity of 40,550 acre-feet. At 120 feet above the base of the dam, which is the height of the new dam now under construction, the length of the reservoir surface will be 11½ miles, the mean width 1 mile, the area of the water surface 7,850 acres, and its maximum capacity 322,000 acre-feet. The dam which closes this reservoir has been frequently described because of the peculiarly bold cross section given it (Fig. 135). It is founded on granite and abuts against firm granite walls on either side. It is 300 feet in length on the crest, is arched upstream with a radius of 335 feet (Fig. 136) and is 64 feet in maximum height. The cross section of the dam is remarkable. The top width is 3·2 feet, the lower face being vertical for 48 feet while the upper face has such a batter that at a depth of 48 feet from the crest it is only 8·5 feet in thickness. At this plane there is an offset up and down stream giving the crest of the lower wall or pedestal on which the upper wall rests a thickness of 12½ feet. Both faces of the lower wall have a slight batter to the foundation which has a thickness of 20 feet. The dam is built of rough ashlar masonry on both faces, filled with coursed rubble masonry in the interior, and laid in uniform beds of Portland cement. The stones used in this structure are of granite and vary in size from 2 to 5 feet in length and from 1 to 2 feet in width and it contains in all about 3,300 cubic yards of masonry.

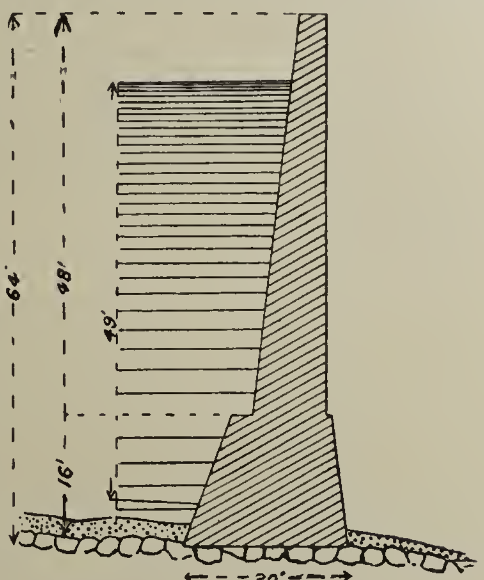


Fig. 135.—Old Bear valley dam. cross section.

The south end of the dam abuts against a massive ledge of granite standing out about 100 feet into the canyon. This ledge really forms a part of the dam, and over it a waste way has been cut having a width of 20 feet and with its sill 8·5 feet below the level of the crest of the dam. Through the bed rock, about 9½ feet below the base of the dam and one-third of its length from the southern end, is a trench in which is a masonry-lined culvert 2 by 3 feet in dimensions, which discharges

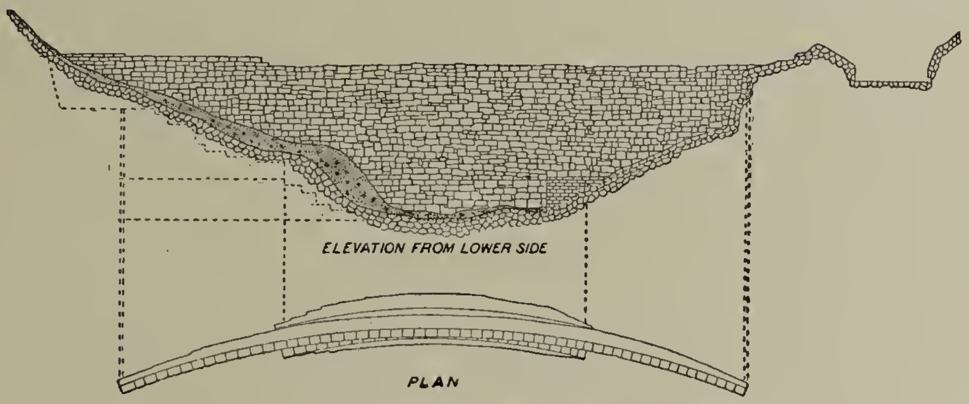


Fig. 136.—Old Bear valley dam. Plan and elevation.

over a weir into a masonry pool from which the water can be measured. On the upper face of the structure the culvert is built in with masonry and has an arched top, the opening being 2 by 3 feet, concrete-lined, and closed by an iron gate. This gate slides on brass bearings and is operated from above by means of a screw. For the last 30 feet at each end of the dam the wall is widened so that it rests against the rock with a thickness of from 1½ to 2 times the normal thickness, thus giving it firm abutments and enabling it to perform its functions as an arch. Frail as is the cross section of this structure, it is a remarkable fact that owing to the excellent manner with which it was built and to the perfection with which the arch action is brought into play it has stood now for nine years through many seasons of heavy flood and shows no signs of weakness.

The Bear valley dam now being constructed is a much larger and more substantial structure than that already described. It is located 150 feet below the present structure and is being similarly built of the best granite masonry, and in plan is arched with its convex side pointing upstream. This dam (Fig. 137) will be about 120 feet in maximum height, its foundation being from 8 to 12 feet deeper than this, while a coping 5 feet in height will be added to the top of the crest. Its upper surface will have a slight batter, while the general outline of the lower face will be about the same as that given by the modern gravity formulas, and will be built in steps having a uniform rise of 10 feet and an offset in proportion to the batter at that point. The top width of the dam will be 15 feet, its extreme width at the base 73½ feet, and the maximum pressure when full is estimated to be 11·6 tons per square foot on the toe of the dam and when empty 9·3 tons per square foot at the upper side.

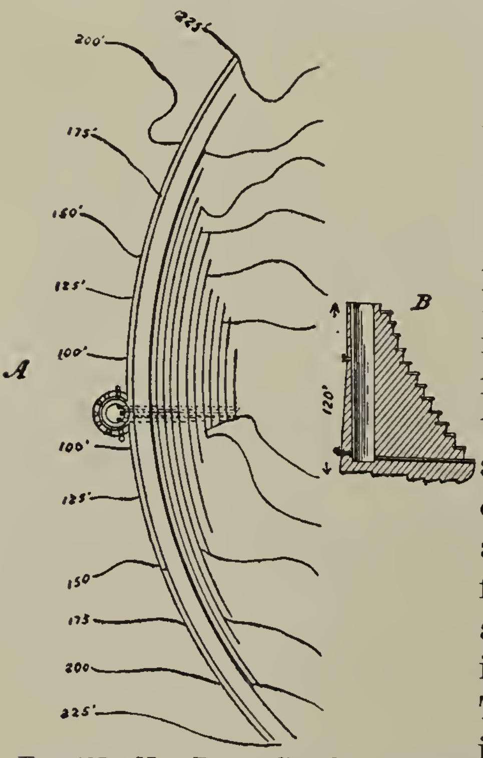


FIG. 137.—New Bear valley dam. Plan and cross section.

The three outlet sluices head in a cylindrical well which extends the entire height of the dam on its upper face. This gate well will be 18 feet in diameter inside and will have 3 inlet pipes at the bottom, 4 more at a plane 40 feet higher, and 3 more at a height of 80 feet from the bottom. They will terminate in iron elbows pointing upward, and will be closed by simple gravity valves similar to those used in the gate tower of the Sweetwater dam. The outlet sluices will consist of 3 cast-iron pipes let through masonry culverts near the bottom of the dam, each being 36 inches in diameter, their entrances being closed by sliding gates worked from the tower, while their total discharge capacity is estimated to be 1,500 second-feet.

The wasteway for the discharge of surplus water in time of flood will be located at the extreme end of the valley 11½ miles from the dam and will discharge into the eastern or desert drainage. The capacity of this reservoir is so great that the watershed of Bear river will be insufficient to fill it in ordinary years. Accordingly a canal has been projected (Fig. 134) which will skirt the eastern slope of the mountains from White river across Mission creek and minor streams and shall empty into the upper end of the basin. This tributary canal will catch the water supply of about 50 additional miles of watershed and it will have an ample cross section to carry these flood waters and add them to those of Bear valley. The total length of the canal will be about 18 miles.

The original dam cost, including all expenses, about $75,000. Just what the proposed new work will cost it is difficult to ascertain. The old company has recently been reorganized with a capital stock of $4,000,000, of which $2,400,000 has been paid for the property of the old Bear Valley Land and Water Company, the Bear Valley Reservoir Company and the Alessandro Development Company, while the remainder will be applied to the construction of works and the purchase of bonds of the Perris and other districts.

The water of the Bear valley reservoir when liberated flows down Bear creek a distance of 12 miles to the Santa Anna river, and an additional 15 miles down this stream to its exit at the foothills, at which point it is diverted. Down these streams it flows over a very steep bowlder bed in which are a number of cataracts with a total descent of 5,200 feet. At present there are diverted from the Santa Anna river two small canals, the North and South Fork ditches, which lead the waters to the irrigable lands in the neighborhood of Redlands. A great pipe line has recently been constructed which carries the water a distance of 10 miles to the Alessandro tract and thence to the Perris district a short distance beyond.

This pipe line is laid in a perfectly direct line from its head on Bear creek, just above the fork of the Santa Anna river, a distance of about 2¼ miles, to the crossing of Mill creek, in which distance it passes over some hilly country; thence it follows somewhat the contour of the country to the low divide separating San Bernardino valley from the San Jacinto plain, in which is situated Alessandro. This pipe line is of steel 28 inches in diameter at first and afterwards reduced to 24 inches. At the divide it terminates in a tunnel 2,300 feet in length, cut through solid rock, the floors and sides of which are lined with a coating of asphaltum. This tunnel is 7 feet high to the summit of the arch; it is 6 feet in width at the springing of the arch, which is 4 feet above the floor, and is 42 feet in width at the bottom, the sides having a straight inclination from the bottom to the spring of the arch.

The roof of this tunnel is of timber. Beyond the tunnel is an additional 2,600 feet of open canal, asphaltum-lined, and beyond this is a small distributing reservoir and the distributing system, consisting of open lined channels, flumes, and pipes of from 6 to 14 inches in diameter. The water is piped to the highest point of each 10-acre lot and is distributed to the plants by means of subirrigation through pipes. The capacity of the main pipe is about 200 second feet and from it are supplied the Alessandro and Perris irrigation districts.

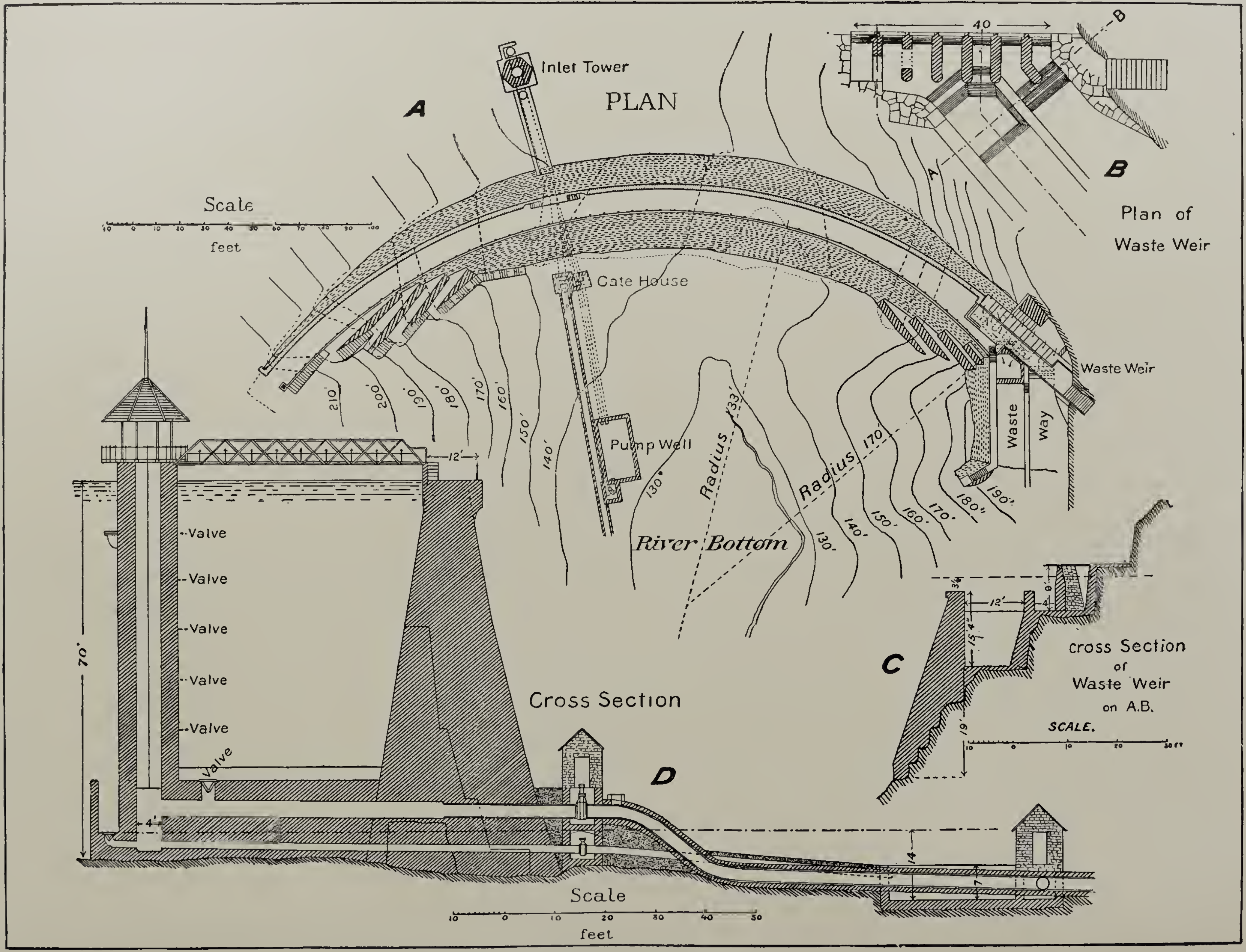
Besides supplying this pipe line and the North and South Fork canals the Bear valley canal is taken out of the mouth of the Santa Anna canyon, and receives much of its supply from the Bear Valley Irrigation Company. This canal heads in a flume 48 inches deep and winds around the bluffs bordering the river a distance of 2,200 feet to the summit of the bench land beyond. Thence the canal is paved and cemented to Mill creek. This cemented channel is 2 feet wide at the bottom and from 3½ to 4 feet in depth. Its grade is from 8 to 20 inches per 100 feet and its capacity about 60 second-feet. The water is carried across Mill creek in a flume 4 feet wide by 2 feet deep and 240 feet in length. Beyond this the canal is again constructed in rock and cemented for about 6 miles, after which it enters the distributing pipes, which serve it to the irrigable lands.

The distributive system so far constructed for the Alessandro tract has cost $80,000 in addition to $100,600 for the main Bear Valley Irrigation Company's pipe line. The distribution to each irrigator is made by well-outlets of 4-inch vitrified pipes, from which the water is caused to rise and overflow through a weir into a service irrigating flume. The main pipe line of the Perris irrigation district heads at the terminus of the Alessandro line and skirts the west side of the Perris district after coming a distance of about 20 miles from its head on Bear creek. This main is of wooden staves, bound with iron hoops, and at first is 30 inches in diameter inside, but is diminished finally to 16 inches in the lower portion of the main. Its projected length is 5½ miles. This West Side system for the Perris district is estimated to cost $157,000, of which $44,000 will be for supply pipes, $50,000 for main delivery pipes, and the remainder for distributive works.

SWEETWATER RESERVOIR.

The Sweetwater dam was constructed by the San Diego Land and Townsite Company to store the flood waters of Sweetwater creek in the hills about 25 miles east of San Diego. This water is used for domestic purposes in National City, a suburb of San Diego, and in irrigating fruit and other lands in the neighborhood of those places. The lands commanded by this reservoir constitute the greater part of the Rancho de la Nacion, most of which was owned by the company constructing the reservoir.

Sweetwater creek heads in the Coast range 40 miles northeast of



SWEETWATER DAM. PLAN, CROSS SECTION, AND DETAILS OF WASTEWAY.

San Diego, immediately under Cuyamaca mountain, and empties into San Diego bay at National City. Its highest permanent source, Green valley, is about 4,500 feet above the sea and is full of springs and cienegas. On its passage to the sea it flows through several canyons and descends precipitately through the rugged mountain slopes. Its maximum flood discharge reaches from 500 to 1,000 second-feet in winter, though during the majority of the year it sinks to a small stream of about 10 second-feet in volume. As the water from this stream is valuable for purposes of irrigation, it was decided to impound the large volume which flows to waste during the winter season. Just how much this amounts to is not known, but it has so far proven sufficient to fill the reservoir each season and still allow a considerable amount to run to waste. Sweetwater reservoir commands the whole of the Sweetwater valley and the mesa lands to the north and south of it, a total of about 20,000 acres, all of which are of excellent quality and are capable of producing the most valuable citrus and semitropic fruits. These lands have been divided into 20-acre lots, forming a sort of city or suburb called Chula Vista, and the company furnishes water in pipes to the highest point of each of these tracts.

The dam is situated in a narrow gorge, 7 miles east of the bay, where the stream flows through a dike of trap rock, leaving above it a broad valley about 3 miles long and from one-third to three-fourths of a mile in width. The construction of the dam was begun in November, 1886. The original plan designed was a narrow wall of concrete masonry 50 feet high, 3 feet wide on top, and 10 feet wide at bottom, arched upstream. After two months' work the plan was disapproved by the management, and Mr. James D. Schuyler was appointed chief engineer. In order to avoid throwing away the work already done, the new work was adapted to the old in such a way as to ultimately increase the length of the dam. The combination of earth and masonry in the original plan was rejected, a gravity profile was adopted, and rubble masonry formed of blocks of stone up to four tons in weight was used as the material of construction. In addition to this an embankment 50 feet wide on top, 10 to 15 feet high across the canyon, and made with clay well rammed in layers was placed against the upper face of the dam. The top of this embankment is 70 feet below the top of the dam.

This dam (Pl. CXLII) is 94 feet in height from the bottom of the foundation to its crest. It is 46 feet in thickness at the base and 12 feet in width on top. The extreme length on top between abutments is 380 feet. Its capacity is 18,000 acre-feet and the batter of the upstream face is 6 on 1 to within 6 feet of the top, above which is a vertical parapet wall. The downstream face starts at the bottom with a batter of 3 on 1 for 25 feet, above which it is changed to 4 on 1 for 32 feet, and then to 6 on 1 to the coping. At the left end of the dam is a wasteway 40 feet in width, consisting of 7 openings so arranged that the water issuing through them shall drop into two series of water cushions, one 2½ feet in depth and the other 6 feet in depth, from which it flows over the steep, rocky walls of the canyon back to the river at a safe distance below the toe of the dam (Pl. CXLIII). Each of the openings of the wasteway is 4 feet wide in the clear, while it is 5 feet below that of the dam. The capacity of the wasteway is 1,500 second-feet, which is greater than any known flood which has occurred in this stream, and this wastage capacity can be increased by 300 second-feet by turning the water through the outlet sluice at the bottom of the dam and permitting it to escape through the blow-off 1,600 feet below.

The water is drawn off from the reservoir into the main conduit through a masonry inlet tower octagonal in plan and supplied with inlet pipes or valves. These are placed about 10 feet apart vertically and consist of cast-iron elbows 24 and 36 inches in diameter, opening upward with bell mouths which are closed with plain cast-iron covers. These covers are raised by means of a simple windlass and chain, operated in the top story of the tower, while at the exit of the outlet sluice pipes at the lower toe of the dam is placed a gate house with valves and air valve by which the further progress of the water can be controlled, while an additional gate house and pumping well are placed 100 feet below the dam in order to give additional control to the operation of the same. A most able description of the construction of this work was given by its designer in a paper read before the American Society of Civil Engineers,[1] while it is further described at length in the report of the State engineer of California.[2] In plan the dam lies in the form of an arch, the radius of which is 213.3 feet for about two-thirds of its length from the right bank. For the remainder of the distance it is planned on a radius of 170 feet, terminating in the wasteway already mentioned. In order to broaden the abutment against the canyon walls the radii are shortened toward the base at either end in such a manner as to cause steps to run out from the dam, thus giving a broader base at the springing of the curved arch and enabling it to act more successfully as an arch.

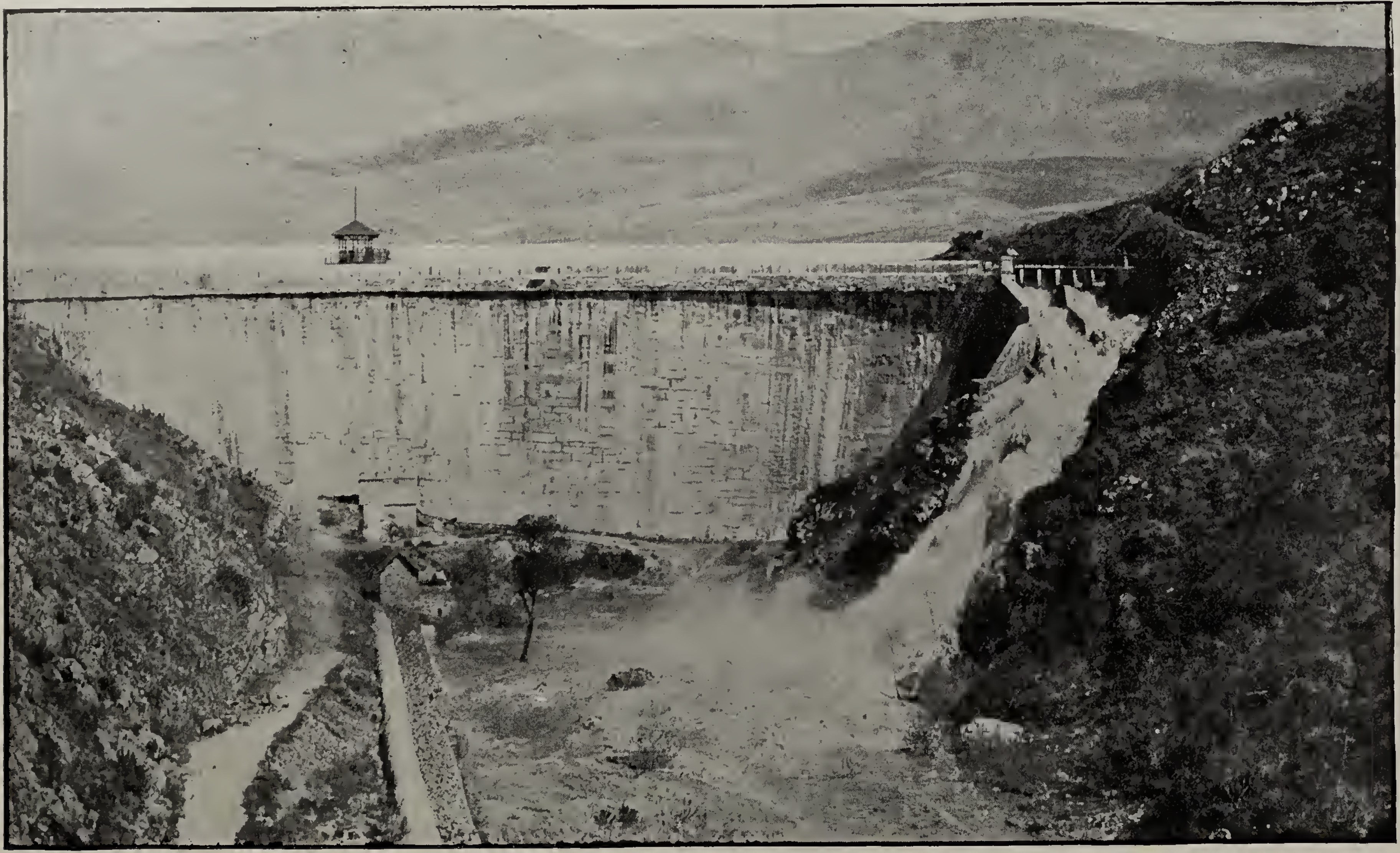
As will be seen from the illustrations the cross section of this dam as finally completed is much lighter than theory would call for in a structure expected to stand by gravity alone. Great reliance has been placed on its curved plan and the shortness of the radius of this curvature, and while much discussion has resulted from this form of cross-section, experience has proven in this case that the work is sufficiently well designed and built to withstand any flood which may be brought against it, and it is commended by the most able engineers as one of the best designed works of its kind ever constructed.

Sweetwater reservoir is situated 140 feet above sea level, which ele-

---

[1] Schuyler, James D. The Construction of the Sweetwater Dam, Transactions American Society of Civil Engineers, New York, vol. XIX, 1888, p. 201.

[2] Hall, William Ham. Irrigation in southern California, Sacramento, 1888, p. 57.



VIEW OF SWEETWATER DAM.

vation is sufficient to enable it to furnish a water supply to all the buildings in the cities below. The surface of the reservoir is 721.8 acres in area and its maximum capacity at 70 feet above the outlet sluice is 18,000 acre-feet. The topography of the reservoir basin is such that 80 per cent of its available capacity is in the upper 30 feet and 60 per cent in the upper 20 feet. Observation has proven that the seepage entering the reservoir from the hillsides adds to the water in the reservoir faster than it loses by evaporation and percolation. The total amount of loss from evaporation alone averages about 6 feet per annum, so that the volume of seepage water entering it is thus seen to be comparatively large. It was expected when the work was constructed that its value for storage purposes would soon be greatly curtailed owing to the deposit of silt brought down by the stream. An estimate made within reasonable limits showed that it would take one thousand years to fill the reservoir.

The distributing system of this reservoir is interesting because owing to the value of the water it is not permitted to flow in open channels but it is conducted throughout in masonry or iron distributing pipes from which it is delivered to the houses or to the irrigable lands. There are three outlet conduits, the two smaller being respectively 14 and 18 inches in diameter, consisting of iron pipes laid side by side and inclosed in masonry. As shown in Pl. CXLII the larger conduit is of masonry, 40 inches in diameter, and terminating in a 36-inch pipe of half-inch wrought iron. The object of the smaller pipes is to furnish a supply for pumping to a higher level than can be reached by gravity and they terminate at the pump house 100 feet below the dam. The 36-inch main is reduced to 30 inches in diameter at the lower end of the canyon 1,600 feet below the dam. From this point it follows the valley for 5 miles and reaches the top of Chula Vista mesa 92 feet above sea level. Its entire length is 29,800 feet and it terminates in two 24-inch pipes, one of wrought iron 2,034 feet in length, the other of wrought steel spiral riveted pipe 5,950 feet in length. At the end of the 36-inch division of the pipe is a blow-off gate affording means of escape for the reservoir. Wrought-iron lap-welded pipes are used throughout the distributing system. The total length of mains and laterals laid to the end of 1888 exceeded 63½ miles in various sizes from 36 inches down to 3 inches in diameter. This work cost in the aggregate $736,838. Of this amount $302,000 were expended in purchase of distributing pipe and $145,000 in laying the same, the total cost of the distributing system being $502,763. The dam cost $87,430 for cement and materials, of which $63,000 was for cement, $140,000 for labor, and its total cost was $234,174. The lands which are flooded by the reservoir below the 50-foot contour cost $27,688, while 350 acres in the upper portion of the reservoir have just been acquired by the company at a much higher rate. Allowing about 90,000,000 cubic feet of water for annual consumption of National City it is estimated that the reservoir will in addition irrigate 20,000 acres of land. The water is not sold separately from the land but the company owning the works and land sell the latter at $100 per acre without water and $300 per acre with water.

OTHER RESERVOIR PROJECTS.

The surveys for the Buchanan reservoir system have been made and detailed plans and estimates for the project completed under the direction of Mr. William Ham. Hall, chief engineer. The site of this reservoir is on the Sharon estate, on what is known as the Berenda-Chowchilla tract, in California. This tract consists of 30,000 acres of irrigable land in Fresno county, California, and the project of which the Buchanan reservoir is a part has as its object the irrigation of this

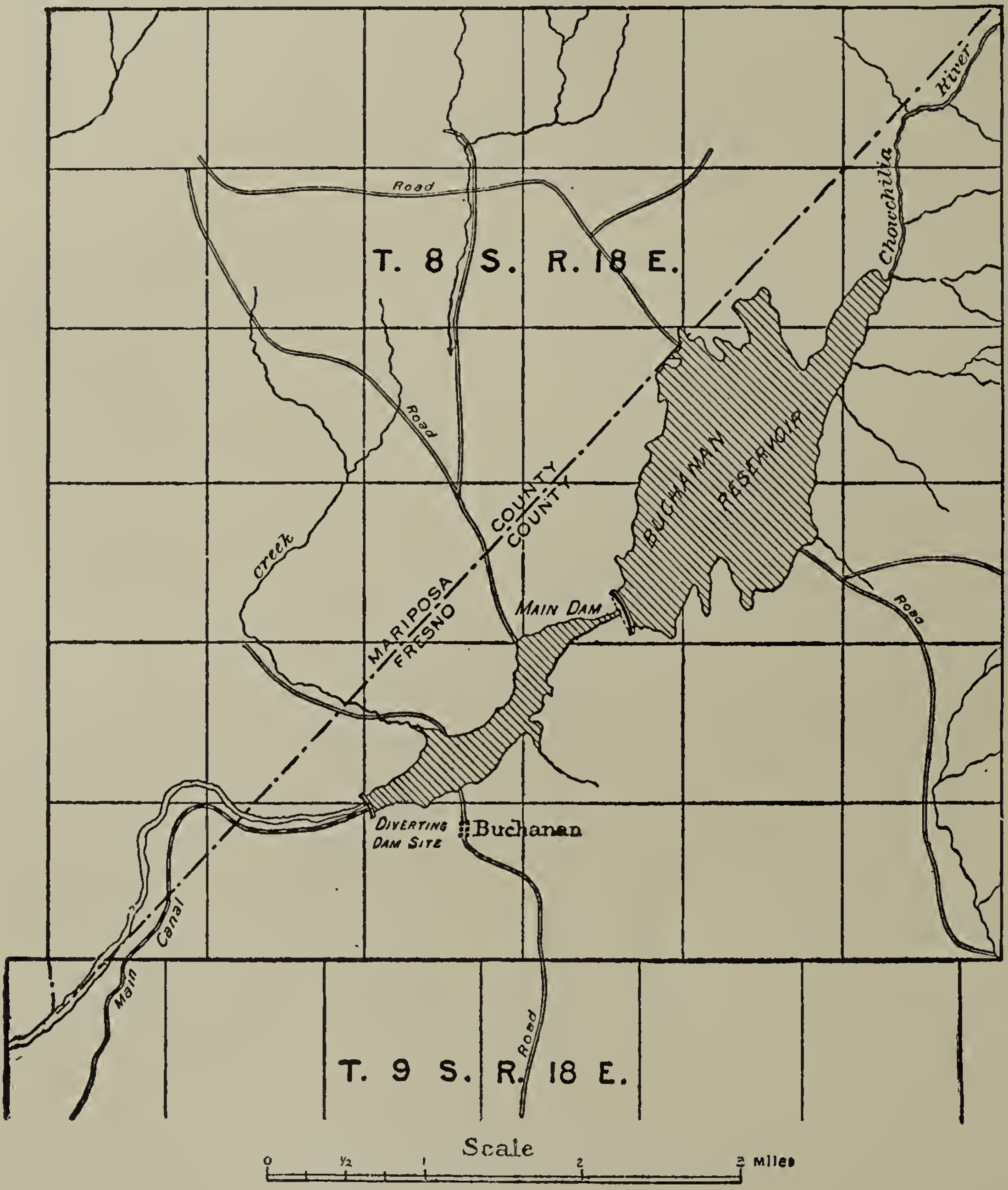


FIG. 138.—Buchanan reservoir system.

land. This project consists (Fig. 138) of the storage reservoir situated on Chowchilla creek, from which the water will be turned into that creek and from which it will be diverted after flowing down it for a distance of 2¼ miles. This diversion will be accomplished by means of a weir and of a main diverting canal which will lead the water to the irrigable lands.

The idea of constructing a reservoir at this site was first conceived years ago, but active surveys were not commenced until the summer of 1890, when they were vigorously pushed to a completion. The perennial discharge of Chowchilla creek is too small to enable it to irrigate much land. During a large portion of the irrigating season it sinks in volume until it becomes a mere rill. Its mean discharge from May till June is but 34 second-feet, though its maximum recorded discharge in times of flood is as much as 1,500 second-feet. While its catchment basin has an area of but 303 square miles, gaugings made on this stream by the state engineer of California in the year 1879 showed a total discharge of 32,000 acre-feet.

The dam, which is to be constructed of uncoursed rubble masonry, is at an altitude of 420 feet above the sea, and will form a reservoir having a superficial area of 1,000 acres and a capacity of 42,400 acre-feet. This, it is believed, will be sufficient to irrigate 26,000 acres of the tract. The maximum height of the dam is 100 feet, its length on the crest is 780 feet, and it is curved upstream with a maximum radius at the center of 1,146 feet, which radius is diminished gradually to 736 feet at the abutments, thus broadening the base on which it rests against the hillsides and increasing its power to act as an arch. Two wasteways will be excavated, one at either end of the dam, the combined discharge capacity of which will be 1,500 second-feet. The entire structure is founded on a firm dioritic rock which outcrops near the surface, and while its cross section is very similar to that given by Wegmann's or other modern formulas, it is made a little heavier than these would require, owing chiefly to its increased width at the abutments. It has a uniform batter on the upstream face of 1 in 25 below the first 10 feet, which are vertical, its downstream face being curved according to theory and producing a maximum width at its base of 68 feet. The top width of the dam is 10 feet, which will be widened by a cornice and 4-foot parapet to 13½ feet. There will be two outlets or discharge channels excavated in solid rock under the dam, at either side of the stream bed, each 20 feet above its base. These discharge sluices will each contain a steel pipe laid in cement and operated by valves from above. In addition to these there will be an undersluice 6 feet above the bottom of the dam, also laid 10 feet deep in the rock under the structure, and in which will likewise be laid a steel pipe.

Water will be diverted from Chowchilla creek by means of an uncoursed rubble masonry weir 12 feet in maximum height and 400 feet long on the crest; this will be a clear overfall weir, and is located on a reef of rock in which is a natural depression at the south end which will be utilized as the canal head. This depression is 30 feet in width below the crest of the weir, and the main canal will head at this point. The canal will have a capacity of 300 second-feet, and will be 4½ miles in length, with no difficulties of construction on its line. At the end of this distance it will be divided into several distributing branches, which will convey the water to the irrigable lands.

The Hemet valley reservoir, which is now under construction in California, will when completed form one of the largest of its kind, while the dam closing it will be nearly the highest and probably the best constructed ever built. The project of the Lake Hemet Water Company includes the storage of water in the reservoir and the diversion of it, and the perennial discharge of the South Fork of Hemet River through pipes and flumes to the irrigable lands in San Jacinto valley. The site for the dam is most favorable, consisting of a narrow gorge through solid granite of excellent building quality. The dam is designed in accordance with one of the modern formulas, though its cross section is slighter than these would demand, as it depends on its curvature to a certain extent for its stability. As at present designed its maximum height will be 150 feet, but its foundation is constructed of sufficient width to enable it to be increased in height to 160 feet if deemed desirable. At a height of 120 feet its length on top will be only 220 feet, and at 160 feet its top length will be but 400 feet. The batter of the upstream face is 10 on 1, while its lower face has a batter of about 2 on 1 to a height of 110 feet, at which point it is changed gradually to 4 on 1. In plan the dam is arched upstream with a radius of 300 feet; its top width is 10 feet, and its thickness at bottom 100 feet.

The dam is constructed throughout of the largest uncoursed rubble masonry, set for a thickness of 10 feet on the upper face in a mortar of one part Portland cement and two parts sand, the remainder of the dam being laid in concrete made of Portland cement one part, sand and crushed stones nine parts. The estimated capacity of the reservoir with a depth of 150 feet will be 26,000 acre-feet and with a depth of 160 feet it would be 32,500 acre feet, sufficient for a constant discharge for 180 days of about 100 second-feet. The chief engineer of this work, Mr. James D. Schuyler, estimates that the water supply for the reservoir will be sufficient to fill it every year to a depth of 160 feet. As at present completed, to a height of 50 feet, the dam is constructed of stones up to 10 tons in weight. Most of the work of building the structure is performed by steam and water power. The rock is quarried at the dam site, and is carried by 2-inch cables a thousand feet in length stretched across the site, on which the stones are transported by trolleys and delivered to derricks, which deposit them at the point required. This work is magnificently designed and constructed, and its length in proportion to its cross section is so short that it is one of the most stable structures of its kind ever built. The lowest outlet to this reservoir is through a 20-inch pipe placed 30 feet above the creek bed, while another similar in design is placed 20 feet higher. The total cost of the work is estimated at $250,000, and the pipes, flumes, and distributive system will cost about $250,000 more.

Another work somewhat similar to that just described is Reservoir No. 1 of the Arrowhead Reservoir Company, the building of which structure is now well under way. The project includes the diversion of the waters of Deep, Holcomb, and other creeks, the headwaters of the Mojave river, on the northern slope of the San Bernardino range in California, and their storage in four large reservoirs, the most easterly being Little Bear valley, or Reservoir No. 1. The water stored in these reservoirs is to be conducted through a tunnel 5,000 feet long, thence in a cement canal to Reservoir No. 3 and through Reservoir No. 4 and other canals and tunnels to the south side of the range, where the water will be used in irrigating lands in San Bernardino valley. On this work will be six tunnels, aggregating 3 miles in length, their dimensions being 8 feet wide by 8½ feet in the clear. The total length of conduits will be about 60 miles, and they are to have a capacity for the delivery of 400 second-feet.

The dam-closing Reservoir No. 1, now under construction, is of masonry and will have a total height of 150 feet, being arched in plan, with a radius of 575 feet. Its cross section will be unusually slight, its length on top being 680 feet and its width at top 10 feet and at the base only 47½ feet. Its total capacity is expected to be about 68,000 acre-feet and its catchment area is 75 square miles, on which the annual precipitation is about 40 inches. The estimated cost of the entire work is $1,500,000.

The Citizen's Water Company, of Denver, Colorado, have now under construction a great reservoir for the storage of water to be used chiefly in the supply of the city of Denver, though it is expected that a small portion of this water will be used in irrigation in and about that city. This project contemplates the collection of water in subsurface gathering galleries under the South Platte river and the construction of two storage reservoirs by mammoth earth dams, one below the other, closing a couple of valleys near Wheatland, a few miles above Denver. These valleys are formed by a couple of hog backs of rock which cross the slope of the country and through which the minor drainage-lines from above have cut outlets. The second dam will be placed half a mile below the upper one and will be of the same height. The slope of the country between the two is such that the lower will raise water against the outer slope of the upper to within 80 feet of its top. The capacity of the upper reservoir site will be about 23,000 acre-feet and its surface area 322 acres, with a mean depth of 57 feet. The lower reservoir will have a surface area of 157 acres and a capacity of 12,000 acre-feet. The drainage or catchment area of these reservoirs is relatively small, being but little larger than that of the basins themselves. The water to fill them is to be brought 19 miles from the South Platte river in a wooden pipe line of 30 inches in diameter.

The basins forming these reservoirs are small and have steep grades. As a consequence of this their capacities would be small unless dams of great height were constructed. As designed by the chief engineer, Mr. C. P. Allen, the upper or main dam, which is now under construction, will consist of an earth embankment 261 feet in maximum height (Fig. 139). Its length will be 705 feet on the crest, its top width 30 feet, its width at base 986 feet. The inner surface will have a uniform slope of about 1 on 3, which will, however, be broken by four benches, each 10 feet in width, the result of which will be to give the surfaces between these benches an average slope of 1 on 2½. The lower or outer slope will be uniformly 1 on 2, but will likewise be broken by benches each 10 feet in width, the result producing an average slope of 1 on 1½. Owing to the steep slope of the country at the point where the dam is built the inner toe of the dam will be 60 feet higher than the outer and 35 feet higher than the bed of the stream immediately under the crest of the dam. The highest water level contemplated is to reach within 15 feet of the top of the dam and will give a maximum depth of 211 feet.

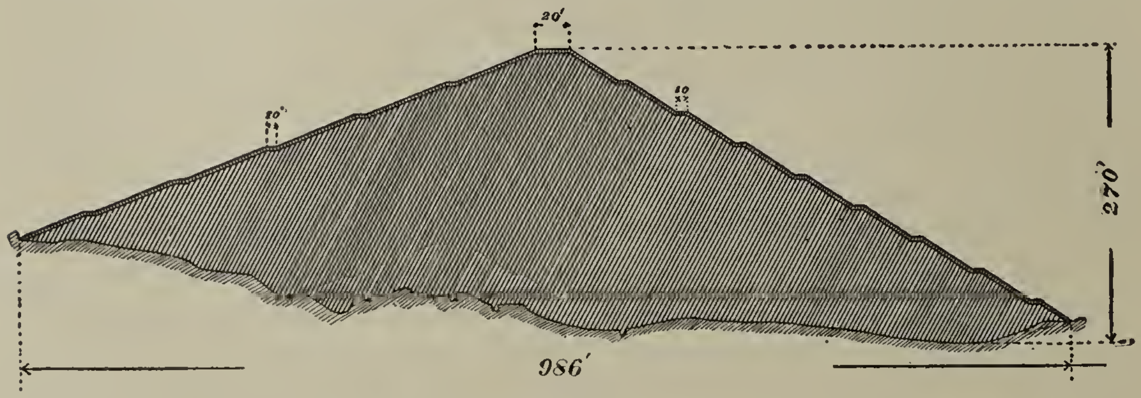


FIG. 139.—Citizen's Water Company dam. Cross section.

The foundation of this dam had been obtained by scraping the surface down to solid rock, in which channels have been cut lengthwise of and across the dam. The earth for the construction of the dam will be taken from the basin and delivered by means of wire tramways. The soil is a gritty clay and will be built up in layers and rolled with a 10-ton roller, the earth being dampened by spray just before rolling. The inner surface of the dam will be faced with 10 inches in thickness of dry paving, which will be lightly bedded in mortar. The cavities in this paving will be filled in with asphalt-concrete, which will also cover the entire face to a depth of about 2 inches. A similar rock facing will be run up the outer slope of the upper dam to a height a little above the level of the water, which will be backed against it from the lower dam.

The dam for the outer or lower reservoir will be constructed on the same general lines as the upper dam. The extreme length on top will be 900 feet and the top width will be 30 feet, the width at base being 989 feet. It will have an extreme height of 235 feet and it will contain 1,500,000 cubic yards of material.

The main upper dam will be entirely homogeneous, with no breaks or openings in it for outlet tunnels or other works. The outlet sluice is to consist of a tunnel through the confining hog-back and a shaft entering the tunnel near its center. This shaft will be sunk near the crest line of the dam and about 200 feet north of the north end to a depth of 155 feet below the high-water line or to within about 55 feet of the bottom of the reservoir. This shaft will be 12 feet in diameter, lined with concrete, and in it a vertical sand pipe of boiler iron will be placed connected with the main outlet pipe, which will be carried from the sand pipe to the outer reservoir and the main distributing conduit through a tunnel 330 feet long, 5 feet wide and 8 feet high. This shaft will be fed from four tunnels connecting it with the reservoir. These will be placed at such intervals apart vertically as to be 35, 75, 120, and 155 feet below the high-water line. In these tunnels will be placed 36-inch intake pipes.

For safety three spillways have been provided at various points on the confining rim of the reservoir. These are in three natural gaps on the north side of the reservoir, which are but a few feet above high-water line, and it is proposed to excavate them to the proper depth, giving each a width of 50 feet. In addition to these there is a main spillway on the south side of the dam which will have a width of 150 feet. (Fig. 140.) Altogether these spillways will have a total width of 300 feet, over which water can flow to a depth of 15 feet without topping the crest of the dam. This upper dam is estimated to contain 1,900,000 cubic yards of earth and to cost $380,000. The cement-laid rock paving for the upper slope will have an area of 39,362 square yards, and will cost $63,000; the shaft and tunnels $25,000; and miscellaneous expenses being $68,000, making the total cost of the upper basin $536,000.

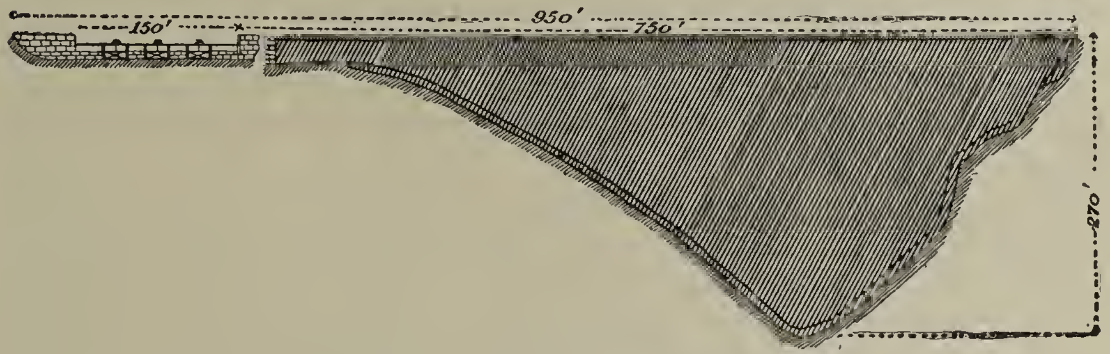


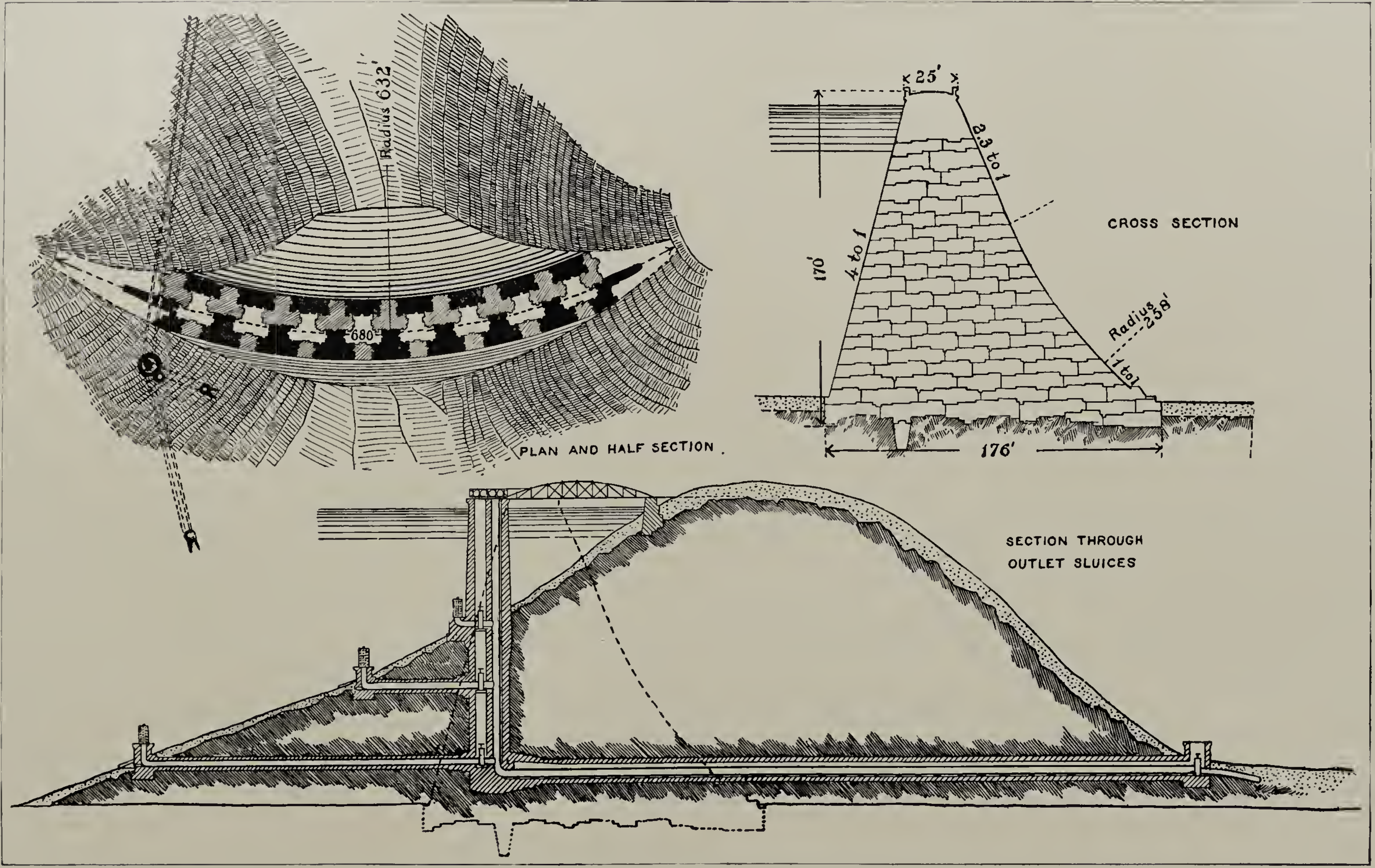
FIG. 140.—Citizen's Water Company dam. Elevation.

Crystal Springs reservoir, near San Mateo, California, is closed by one of the largest and finest masonry dams ever constructed. This work is the property of the Spring Valley Water Company of San Francisco, and provides a portion of the water supply for the city of San Francisco. It is of interest, however, in connection with the consideration of storage reservoirs for purposes of irrigation, because of the excellence of its design and the fact that it is built in the arid regions and that similar structures may be erected for storing waters for irrigation.

The catchment basin of the reservoir is not large, but as it is situated in the Coast Range, where the rainfall is relatively great, it has been found amply sufficient to fill the reservoir in all ordinary years. The cross section of this dam is nearly that which would be given by one of the modern gravity formulas, though it is made a little heavier than theory alone would require (Pl. CXLIV). Its maximum height is 170 feet, its crest being 5 feet above high-water mark, and 25 feet in width, giving an ample roadway. The width of the dam at the base is 176 feet. The upper slope has a uniform batter of 4 on 1, while the lower slope, beginning with a batter of 2¼ on 1 near the top, curves with a still greater slope and radius of 258 feet to within a few feet of the bottom, where the batter becomes 1 on 1. The storage capacity of this reservoir is 92,000 acre-feet, the shape of the reservoir being rather peculiar and consisting of a flattened-out valley, the exit of which is through a very narrow opening between excellent and steep rock slopes in which the dam is constructed (Pl. CXLV). The total length of this dam on the crest is 680 feet and it is curved with a radius of 637 feet, the convex surface facing upstream (Pl. CXLIV).

The method of construction of this work is peculiar; the foundation was first excavated through a gravel-bed about 8 feet in thickness, and through bed rock to a depth of perhaps 6 feet a trench was cut the entire length of the dam at a distance of about one-third the width of the dam from the upper face, thus giving the structure a firm hold on the bed rock. The dam is composed of great concrete blocks of uniformly irregular dimensions, which weigh 9 tons each and were built up in the body of the dam in such manner as to key with each other both in horizontal and vertical plan, so as to produce a nearly homogeneous mass and create the greatest amount of friction between the blocks. The material for these blocks was mixed at the site of the dam, run out in a tramway and built in place by means of wooden boxing, which was afterward removed. The concrete consists of 2-inch gauge metal and was mixed in the proportion of 6 of broken rock metaling, 2 of sand, and 1 of the best Portland cement. These blocks were left surrounded by the wooden boxing for one week, during which time they set sufficiently for the wood to be removed and to permit other blocks to be built against them.

The northern end of the dam abuts firmly against a small hill, which is about 3 feet in width at the level of the crest of the dam. On the opposite side of this hill is a low divide 25 feet in maximum depth be-



SAN MATEO DAM. PLAN, CROSS SECTION, AND OUTLET SLUICES.

low the dam crest, in which a secondary dam has been built. This consists of a simple wall of masonry slightly curved upstream, 12 feet in width and sunk through the gravel to bed rock a total depth of about 130 feet from the crest. This wall is built of concrete bedded in place and in case of high floods the spillway for the dam will be over this secondary wall, the water having a sheer drop of perhaps 25 feet.

The outlet sluice for this structure consists of tunnels let into the hillside near one end of the dam in such manner as to not imperil the integrity of the structure. (Pl. CXLIV.) On the upper side are three inlet tunnels placed at equal distances apart vertically, the lower one being on a level with the bottom of the reservoir and the upper one about 80 feet below the surface. These tunnels are substantially lined with masonry, and in them are laid iron pipes which discharge through a solid masony inlet tower, the inner diameter of which is 14 feet, into a cast-iron standpipe 50 inches in diameter erected in the center of the tower and reaching to a level with the crest of the dam. From this standpipe at its lower end is built a one-fourth inch steel pipe 54 inches in diameter, which runs through an outlet tunnel of masonry so constructed that the line of the pipe can be at any time inspected. At the lower end of the outlet pipe is a valve chamber from which a wrought-iron distributing pipe 44 inches in diameter leads the water away.

CONSTRUCTION OF DAMS.

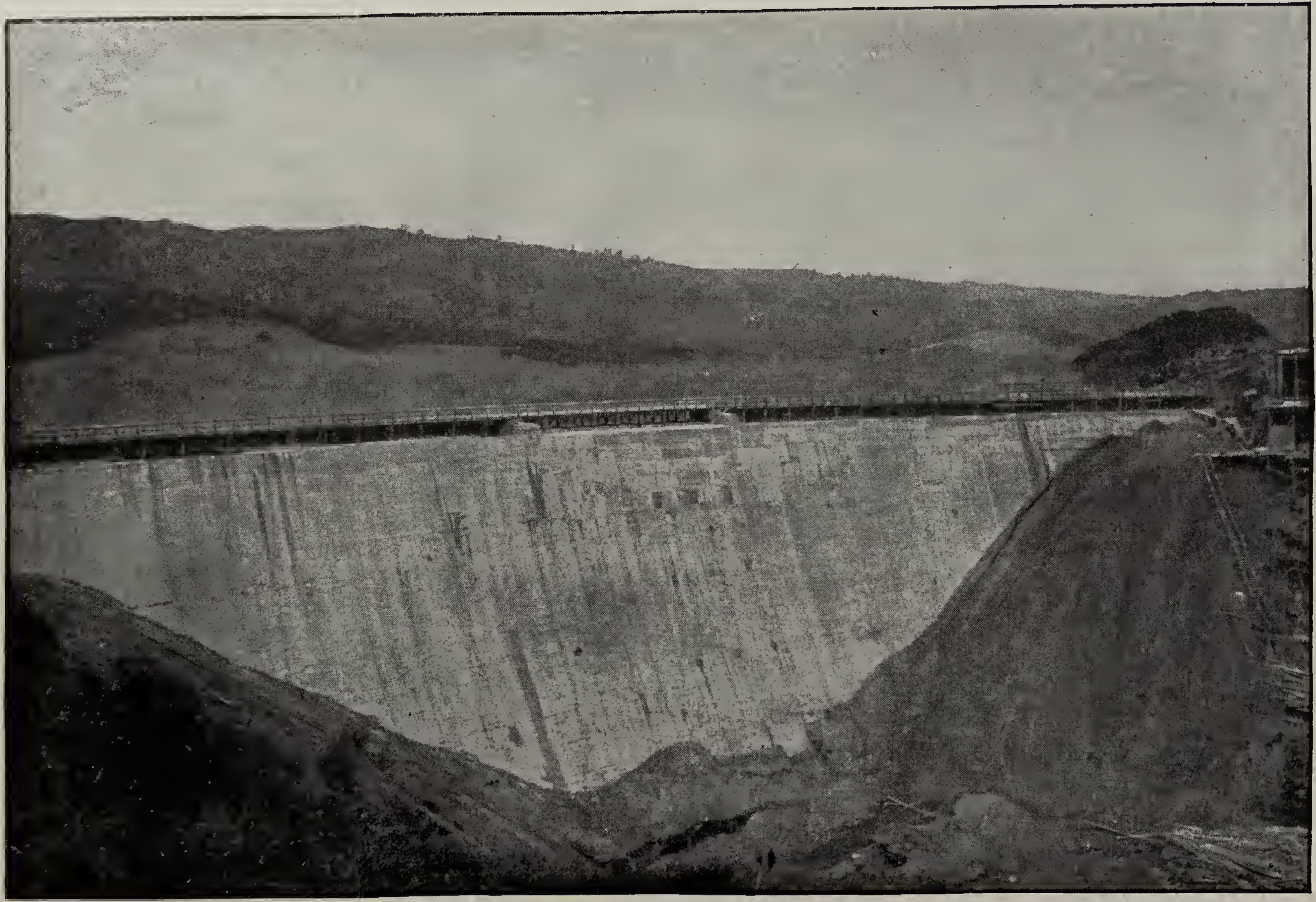
The methods employed in the construction of earthen, loose rock, or masonry dams for purposes of water storage in the arid West differ in no particular from those employed in constructing storage works for city water supply in the eastern states, or in the construction of similar works in Europe and elsewhere. They are essentially the result of the experience of older countries and engineers, with the exception only of what is known as the loose-rock dam, which is a development of the hydraulic mining type of dam employed first in the storage of water for hydraulic mining purposes in California.

In the design of masonry dams the cross section is usually patterned on one of the theoretical formulas which are an outgrowth of the Sazilly, Delocre, Rankin, or other formulas of the same kind. The chief idea of this design is to obtain a structure which will contain the minimum amount of material for the maximum strength. Such works are never built with the expectation that water will flow over them. The dam closing the Crystal springs reservoir, in California, which is heavier than theory demands, served, however, as a flood overflow weir during its construction, and large volumes of water were passed over its crest without injury to it. The Folsom and Turlock dams have likewise both been built on exceptionally heavy cross sections, in order that they might act as overflow weirs, and great bodies of water have passed over both of these structures without in any way injuring their stability.

In the design of masonry dams for western practice three notable features are to be observed. In the case of the Folsom and Turlock dams, great structures of masonry, averaging 100 feet in height, have been erected, over which it is intended that floods from 20 to 30 feet in depth shall pass. Nothing on so magnificent a scale has ever before been attempted in any part of the world. In the construction of the Crystal springs dam, the engineer has erected the highest and most massive structure of its kind yet attempted, while he has built it on plans essentially different from those heretofore employed. It is not of stone set in cement, as is ordinarily the case, but, like the great Periar dam, of India, is wholly of concrete. While the Periar dam is built as a homogeneous mass or monolith of concrete, the Crystal springs dam is built of concrete blocks, so that when completed it is similar in construction to a work which might have been built of uncoursed ashlar masonry blocks of an average of 9 tons in weight.

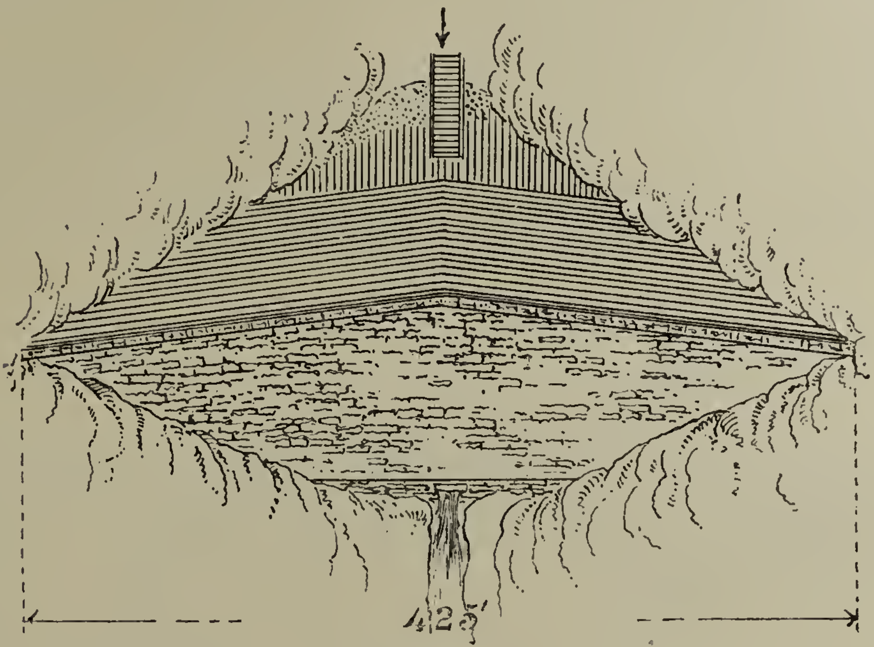
The third peculiar feature in masonry construction observable in western practice is the boldness of cross section sometimes given combined with the curved plan, thus causing the structure to resist the tendencies to overturn it largely because of its action as an arch. The two most notable instances of this form of structure are the Sweetwater and Bear valley dams. That both of these depend largely on their curved plan for their stability there can be no doubt. While engineers have wondered at the lightness of the cross section of the Bear valley dam the fact remains that it has withstood floods of great magnitude during the eight years which it has been in existence and shows no signs of weakening. The Sweetwater dam is built on a cross section similar to that which would be obtained from a gravity formula, but has been made so much lighter than these would permit, the center of pressure falling without the middle third, that it is readily acknowledged that for its stability it is largely dependent on its arched plan. The Bear valley dam, however, has such a light cross section that without the arched plan it would be immediately overturned. The Buchanan dam in California has been designed on a curved plan, and the chief interest in this structure lies in the manner in which the radii have been changed at different levels near the extremities of the dam so as to give it a broader bearing on its abutments.

In the construction of masonry dams the western engineer employs machinery to as great an extent as is possible in order to diminish the cost, since labor is high, while various ingenious mechanical contrivances are resorted to both in transporting materials and in handling the regulating gates of the structures after their completion. A unique illustration of the latter device is the great weir shutter on top of the Folsom dam. The ingenious method employed at the Turlock dam in order to enable the regulating gates to be operated under a great flood height is of interest. This consists in heading the canal in a tunnel, the face and walls of which act as the walls of the regulating gate

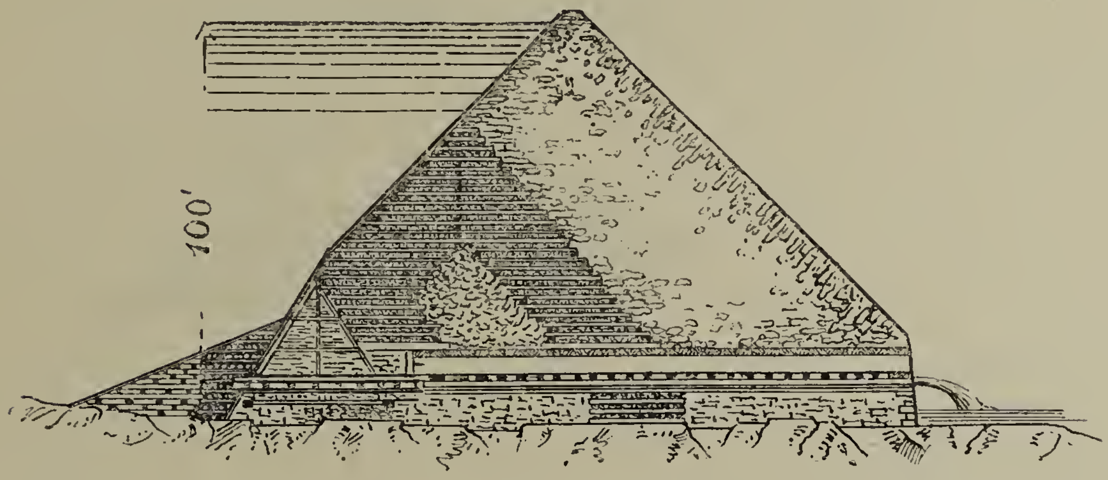


VIEW OF SAN MATEO DAM.

and withstand the pressure of high floods which would otherwise be brought against the gates and necessitate their having increased height. During the construction of the Folsom, Turlock, Hemet valley, and new Bear valley dams wire cables were suspended overhead and on them ran various forms of trolleys employed to hasten and cheapen operations.



PLAN

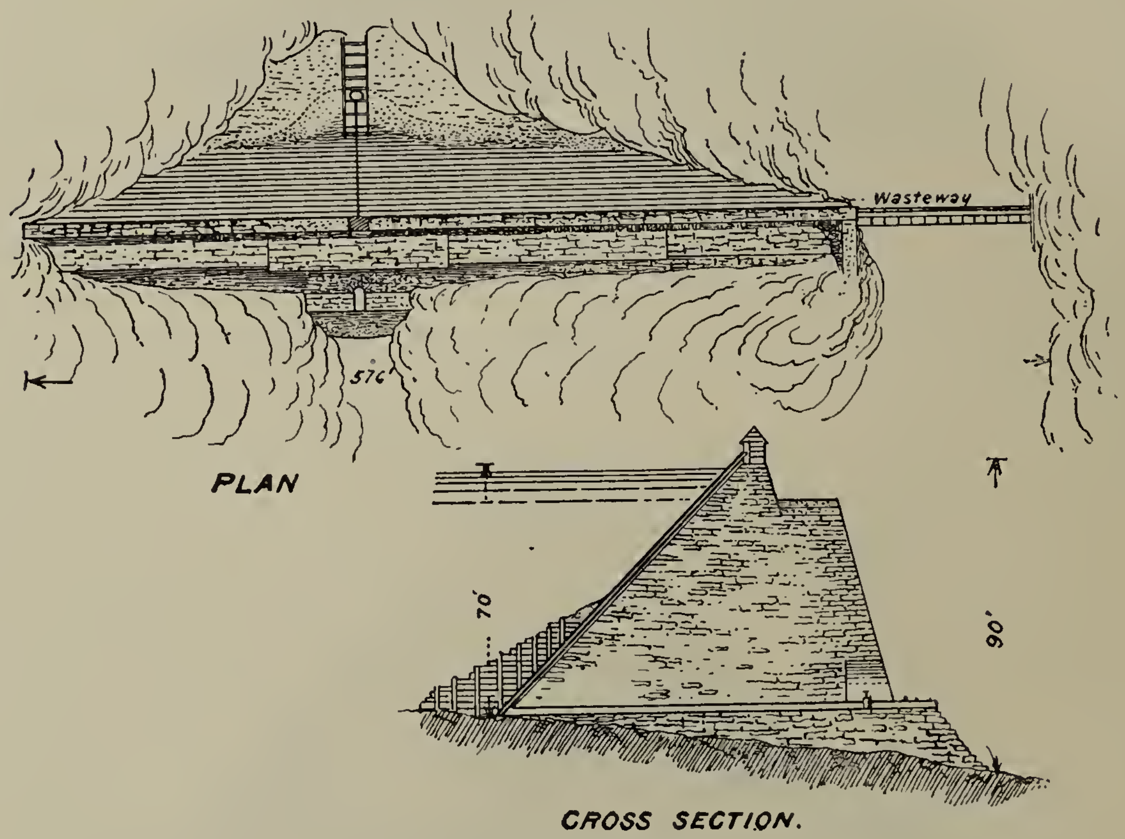


CROSS SECTION

FIG. 141.—Bowman dam.

Rock-filled dams, as before stated, are peculiarly an outgrowth of western practice. A combination of crib work and rock-filled dam has been built in several cases, and has answered the purposes for which it was constructed most admirably. Such is the Bowman dam which supplies the north Bloomfield mines in California with water for hydraulic purposes. As shown in Fig. 141, this dam has a total height of about 100 feet and uniform slopes on both faces of 1 on 1. The lower third of this dam on the upstream side was built of crib work filled with rocks, while the remainder of the structure was built of loose rock carefully hand-laid. Near the bottom is built in masonry an outlet tunnel or sluice, and this work has been in constant use for ten years, and is still as firm as when constructed. The English dam, situated not far from the Bowman dam, was built on similar designs and answered its purpose equally well.

The Fordyce dam, also built in the mining region of California, is a good example of a simple, loose-rock dam. This structure (Fig. 142) is 70 feet in maximum height and 90 feet in width at the base, its top width being 6 feet and the batter on the lower slope 4 on 1, while the upstream face has a slope of 1 on 1. The outer walls of this dam are laid up in dry masonry carefully placed by hand, the inner mass of the structure is filled with loose rock and the prevention of leakage is secured by a facing of plank on the water side, three inches in thickness laid on 12 by 12 stringers, which are built into the body of the structure and are from 10 to 12 feet in length.


PLAN

CROSS SECTION.

FIG. 142.—Fordycé dam.

The most effective form of loose-rock dam is one which is founded on firm rock or a deep bed of clay and in which the materials are placed with some degree of care by hand, so that little or no settlement may take place after its completion. No water should be allowed to pass over the crest of a loose-rock dam, and an ample wasteway should be constructed at one side of it. The top width is rarely made less than 8 or 10 feet, and the slopes down stream vary between 1 and $1\frac{1}{4}$ on 1, the upstream slope being steeper, perhaps 2 to 3 on 1.

An effective form of combined dam has been employed in the west in the last few years, the most notable examples being the dams at the heads of the Pecos and Boise canals. These consist of a wall of loose rock, very similar in its general dimensions to those of simple loose-rock dams, while the upstream slope is backed or reënforced by a heavy earth embankment, rendering the structure impervious to water and increasing its stability. This earth backing is given a thickness of about 10 feet and a slope of 1 on 2½ to 3, the water surface being riprapped or paved as in any other earthen dam.

In the construction of earth dams there is still less diversity from eastern and foreign practice than in masonry dams. The practice ot building a puddle wall, usually starting in a puddle trench and extending the entire height and length of the dam, is still adhered to; though in a few of the more recent structures selected material carefully laid in layers and well rolled and tramped over is coming more into favor. Two of the most notable instances of structures of this kind are the Merced dam, which, owing to the lack of water, was laid dry and has shown no signs of leaking or of weakness, owing to the care with which the materials were selected and packed; and the Citizens Water Company dam at Denver, which is to be a great earthern structure higher than any other dam in existence; the materials of which were selected and carefully tramped and rolled. The slopes given to earth dams as constructed in the west show nothing that is peculiar, and are generally made safe for the material of which they are built.

One of the most commendable things in the construction of earth dams in the west is the fact that such composite structures as earth dams with masonry cores or heavy puddle walls are rarely built, the chief protection employed being in the selection of materials in their emplacement. An interesting attempt at the selection of material was that made in the earthen dam across Delaney gulch on the Turlock canal. This dam is 40 feet high and 180 feet long on the crest and has a top width of 20 feet and slopes of 1 on 2. Its outer face is of coarse gravel, the inner face being clay, while the central mass of the dam is of sand and small gravel moistened and puddled and tramped over by horses. This structure was built, however, not as a puddle wall, but the whole dam was built up in layers, each layer consisting of three classes of materials. In the foundation a puddle trench 14 feet wide and 14 feet deep was excavated to prevent the passage of subsurface water, and this puddle trench was filled up with a puddle wall rising about 8 feet above the general surface of the ground into the mass of the dam.

CHAPTER VIII.

SUBSURFACE SOURCES OF SUPPLY.

Under this title are included all those sources of water supply which are obtained by mining, digging, or boring. It is a well-known fact that in many regions the subsurface water level rises very nearly to the surface, while nearly everywhere water is to be found at some greater or lesser depth. This ground water in some cases may be nearly inexhaustible; in others of very limited amount. Where there is a sufficient slope, as in the plains east of the Rocky mountains, this ground water is so well distributed and so great in amount that it is frequently, though incorrectly, spoken of as the "underflow." This is not an accucurate description, as the water does not flow under the soil, though there is a slow and constant creeping motion along the general slopes, due chiefly to capillary attraction, and to a much lesser extent to the action of gravity. It is probable that the motion of any particle of water is not much more rapid than it would be if acted upon by capillary attraction alone. These ground water supplies are are situated at various depths. Those which will not rise to the surface of the land when exposed by wells or borings may be properly designated ground or spring level supplies. Those which, when exposed or given a free outlet rise to the surface, from natural causes, are known as artesian supplies.

Large volumes of water obtained from these sources in various portions of the West are devoted to irrigation. In the East and in Europe we are familiar with them, and throughout the interior of the land away from cities nearly all domestic supplies are received from this source through wells or springs. In India, Italy, and Egypt great areas of land are irrigated from the ground water supplies which are raised by pumping, while to a limited extent in these countries, but to a great extent in Algeria, artesian wells are used for the irrigation of land. Only within recent years have American irrigators devoted their attention to the utilization of these water sources. Wells from which the water must be raised by pumping are as yet employed in this country to such an extremely limited extent as to deserve no more than a passing mention. Water supplies from a variety of springs known as "cienegas" have been developed to a greater extent, and comparatively extensive areas are irrigated from these in Los Angeles and San Bernardino counties and elsewhere in southern California.

The subsurface waters which flow under the dry beds of the mountain torrents and streams abounding in the southern arid region will in the future furnish a moderate supply for irrigation, and already several of these supplies have been developed. They are extremely interesting because of the engineering devices required in rendering them available. Many hundreds of artesian wells have already been bored in all portions of the arid regions, and they have resulted in the development of a very extensive source of supply, which is destined to increase in volume. Ordinarily the individual supplies derived from this source only suffices for the requirements of domestic use, but there are many large wells, the discharge of which is sufficient to irrigate considerable areas of land.

Experience has proven that, while the volume of ground water may be relatively small before irrigation is practiced, shortly after the introduction of canals and irrigation the spring water level begins to rise owing to the filling up of the soil with water. This rise may reach such proportions as to endanger the soil and impede the progress of irrigation providing the surface slopes of the country are flat. It may result in souring the soil, in water-logging or in the production of efflorescent and alkaline salts. If the country has such a slope, however, as to give a proper natural drainage, these evil effects rarely result, while an abundant volume of ground water is created furnishing water for domestic use or for wells from which it may be pumped to irrigate the land. In India most of the water applied from gravity canals is used over again through wells to irrigate portions on which gravity irrigation is not practiced, thus nearly doubling the duty of water.[1] Similar results from irrigation have taken place not only in Italy and Egypt but also in our own country. In the Sacramento valley, California, in the neighborhood of Boise, Idaho, and on the plains of Colorado and elsewhere, irrigation has caused an appreciable rise in the ground water and has rendered it possible to obtain well water at a moderate depth where before it was either unobtainable or it was necessary to dig the wells of great depth.

It is not proposed to treat here of the origin or theory of artesian wells. Much has been written on the subject and the few scientific or engineering considerations involved are of especial interest to the geologist rather than to the engineer. The development of the ground water under stream beds, the hillsides or the prairie slopes in California, Colorado, and in similar regions offers the greatest field for engineering ingenuity.

Submerged dams have been built in California across dry stream beds with the object of cutting off the subterranean flow and bringing the water to the surface. The presence of this water has been determined by the sinking of shafts across the channel and measuring the volume of flow by pumping. Subsurface canals or tunnels have been constructed in some of the canyons of California and especially on the

---

[1] Wilson, H. M. Irrigation in India, Twelfth Ann. Rep., U. S. Geol. Survey, pt. 2, Washington, D. C., 1891, p. 423.

Platte river in Colorado for the development of these ground waters. This operation has been very aptly termed "mining for water."

In Colorado some experiments have been made to ascertain the volume and movement of the ground water.[1] At Dodge city and Hartland the amount of water obtained was 15 second-feet for each mile in length of the excavation which was made 6 feet below the ground water level. It was found that the width of the canal had but little effect on the amount of water entering it. The depth and length are the controlling factors, other conditions being equal. These subcanals are simple drainage channels extending up and along the side of the river beds until the bottom of the channel reaches about 6 feet below the original water line, when the channel is given the same grade as the river and extended as far upstream as circumstances will admit. Mr. Nettleton found that a depth of about 6 feet below the water line was the proper one. Calculations regarding the proportional increase of the flow due to deeper cut channels showed it to be nearly as the square of the depth. This rule was verified by the subconduit under the bed of the South Platte river 25 miles west from Denver. This subconduit is 18 feet below water line. The inflow proved to be about ten times the quantity obtained from a subchannel 6 feet in depth.

The depressed canal which has been constructed near Hartland, Kansas., by Mr. G. W. Potter, for the supply of the southwestern canal by collecting the ground water, offers an interesting example of this class of work. The excavation was commenced when the river was dry, in September, 1890, and was completed in a few months. The Arkansas river at this point has a grade of 7 feet per mile, while the depressed supply canal has a fall of 3 feet to the mile and is 18 feet in width at the bottom. This canal approaches the river until it reaches within 100 feet of the north bank when it continues parallel with it and at a corresponding grade. Two thousand feet from the place of beginning water was struck in a sand substratum. Beyond this the inflow of water as shown by measurement increased rapidly as the canal progressed until after 7,900 feet had been excavated it was found that this volume amounted to nearly 20 second-feet.

Tunnels for the collection of subsurface water have been run under stream beds in different parts of the West, and their operation is simple and very similar to that of tunneling for any other purpose. The old water supply for the North and South fork ditches in San Bernardino valley was derived directly from the river through a tunnel heading on a level with the stream bed. Recently a tunnel to collect ground water has been driven under the bed of the stream and parallel to its course. The river bed at this point is of gravel and bowlders and the water which flows down to this point is lost by seepage. In order to build a dam down to bed rock for purposes of diversion, it would have been necessary to go up the river several miles, necessitating a very expensive conduit. The water was accordingly permitted to sink into the stream bed and a channel run under the bed to catch it. This tunnel is 2,000 feet long, its cross section being 3 by 3 feet inside. The upper portion is curved in an oval form. This tunnel is lined with loose rock and bowlders, with some pointing of cement to hold it together. It heads under a rock point where the old Northside and Southside canals head and terminates in a diverting flume 2,000 feet lower down. The cost of driving this tunnel was between $5 and $6 per running foot, and it collects about 9 second-feet of water.

---

[1] Nettleton, Edwin S. Progress Report of Artesian and Underflow Investigations, pt. 2, Agricultural Department, Washington, 1891, p. 9.

An interesting venture in water development is that of the East Whittier Land and Water Company in southern California. This corporation was organized in the spring of 1890. Its water supply is derived from lands near the west end of the San Gabriel bridge. Work was commenced early in the summer of 1890, and consisted chiefly in deep cutting and some tunneling, the object of which was to develop some artesian wells which do not flow quite to the surface. Already 14 artesian wells from 80 to 200 feet in depth have been developed, their total discharge amounting to about 10 second-feet; though it is anticipated that two or three times this volume will be ultimately obtained. The works consist of a cutting lined with a wooden flume 4 by 6 feet in cross section. This cutting is about 3,600 feet in length and terminates in a flume and trestle 4,300 feet in length which cross the river. This trestle rests on piling driven from 10 to 16 feet into the bed of the river, and beyond it are the distributing channels. Along the line of the deep cutting, in which a flume is laid, are several artesian wells which have been tapped by short tunnels which strike them on a level with their highest rise.

The Ontario Colony in San Bernardino county, California, derives its water supply from a tunnel. The land commanded by this enterprise lies immediately west of Cucamonga wash, and on the slope of the plain lying between the foot of the mountains and the Southern Pacific railway. This plain has a steep slope and the land is of the most excellent character for the cultivation of citrus and semi-tropic fruits. A large portion of the water supply of this company is derived from a tunnel driven into the gravel bed of the canyon a distance of 2,850 feet. This tunnel is 3 feet 4 inches wide at the top and 6 feet high. It was badly aligned as there are several abrupt turns in it made to meet air shafts which had been previously sunk out of line. Its grade varies between 30 and 70 feet in 1 mile. It was commenced in January, 1883, and completed after several interruptions in 1888. It is timbered with 8 by 8 redwood in bents spaced 4 feet apart backed by 2-inch lagging on the top and sides. The floor has been paved with concrete 4 inches in thickness and in some places concrete walls have been run up to a short height. This was done because of the caving in of a small portion of the tunnel. From the mouth of the tunnel is laid a rock and cement lined ditch 3½ feet wide and 1½ feet deep for a distance of 2,000 feet, beyond which are laid distributing conduits and pipes. This tunnel cost from $4.50 to $5 per linear foot exclusive of that portion of the tunnel which is masonry lined, while the entire tunnel cost about $50,000.

The water supply of the Citizen's Water Company, of Denver, Colorado, is derived from a series of tunnels or galleries which are run under the Platte river and lined with crib work. This company was organized in 1888 and their efforts have since been directed to the development of water from the South Platte river near the canyon. The enterprise contemplates the development of these underground waters and the impounding of surface water in the great reservoir described elsewhere in this report. The underground gathering galleries consist of perforated pipes and open crib work at a depth of from 14 to 22 feet below the surface of the gravel bed of the stream. The cribs are each 30 inches square and about 4,000 linear feet of these have been already built, besides which there have been laid over 4,000 feet of perforated iron pipe 30 inches in diameter. In addition to these main galleries there have been constructed 2,500 feet of branch galleries.

An average daily yield of 435,000 cubic feet or about 10 acre-feet of water has already been obtained and the company is now extending the cribs at the upper end for a distance of 100 feet. This work will be done by the construction of a tunnel, as the cost of making an open cut would be excessively great. It is anticipated that this tunnel will add about 400,000 additional cubic feet to the capacity of the galleries.

Another interesting scheme for obtaining a water supply from a subsurface source is that of the American Water Company of Denver, Colorado. This work consists of a submerged open crib dam in the gravel and sand bed of Cherry creek and resting on solid rock which is about 73 feet below the bed of the stream. This crib work is placed near the right bank of the stream and is 70 feet in maximum height, its crest being 3 feet below the water service. Its total width across the channel of the stream is 700 feet, though the total width of the stream channel is more than twice this. This crib work is not properly a dam, as it does not cross the entire channel and stop the movement of the ground water, but merely catches a certain amount of this water. The dam is 10 feet in width at its crest and 17 feet in width at the bottom. It consists of crib timbers 14 inches in dimension at the bottom, decreasing to 8 inches at the top. These timbers are placed 4 feet apart across stream. Vertical 3-inch planking is fastened on both sides of the dam close together so that it is water-tight on the lower side while on the upper side the planks are placed 3 inches apart. The cribs are drift bolted and are also held together with long stay bolts 4 feet apart vertically, connecting the front and back sides. The dam is being sunk by building it on a great iron shoe which is laid 40 feet below the surface in an open dredged cut and for the rest of the depth it is sunk by excavating its interior and weighting it so that it falls by its own weight and with the aid of the cutting edge of the shoe.

A pump pit or well is sunk from the hill to nearly the same level as the bottom of the dam, the pit being 72 feet deep and lined with stone masonry, the walls 5 feet thick. Its inner diameter is 24 feet, while at the bottom is a gallery 150 feet long, in which are pumps. Two cast-iron suction pipes are laid from the bottom of the pit to the interior cells of the crib dam and the water is pumped to a storage reservoir to be located on a hill near by.

The most interesting submerged dam yet constructed is that on the Pacoima creek at the Maclay ranch. This dam is the property of the San Fernando Land and Water Company, and was constructed by developing the water which was known to flow under the dry gravel bed of this stream during the most of the irrigating season. This stream discharges a comparatively good volume of water in the hills some distance above the dam but sinks and disappears before it reaches the plains. In times of flood the river discharge is considerable, and this is permitted to flow off over the dam, the crest of which toward its end is a little higher than the level of the stream, but is about on a level with the stream bed near the center of the channel.

At the site of the dam the canyon walls are about 800 feet apart and bed rock is generally from 25 to 50 feet below the gravel surface of the stream. A trench from 5 to 7 feet in width was excavated across the stream bed from wall to wall, and was timbered and lagged. In this a wall of bowlders laid in cement was built up, being 600 feet in length, 2 feet in width at top and about 3 feet in width at bottom. Its greatest depth is 52 feet, its average depth being 45 feet. It reaches in some places to a height of from 2 to 3 feet above the surface of the stream bed. This dam extends down and is cemented to bed rock for the entire distance across the bed of the stream. The trench in which it is built was excavated in sections of about 80 feet in length, in which the wall was built up a section at a time, and when completed the gravel and sand were thrown back around the dam, thus completely inclosing it.

On the line of the dam (Fig. 143) were built two wells of masonry as a part of the structure itself. These wells are 4 feet in interior diameter and 1 foot in thickness on the upper side and 2 feet in thickness on the lower side. They are let down to the full depth of the dam and have a few openings in them to admit percolation water. The dam itself is built in a straight line in such a manner that it completely shuts off the flow of subterranean water and forms a submerged reservoir in the gravel which is about one-half mile in width and several miles in length, and averages nearly 30 feet in depth. Water is collected by means of parallel line of pipe 10 and 12 inches in diameter laid on the upper side of the dam next to the wall in four horizontal rows. These rows are placed from 8 to 10 feet apart vertically, beginning near and parallel to the bed-rock, and are laid in 2½ feet lengths, disjointed in such a manner that the ends are about half an inch apart and the openings are surrounded by stones. These pipes are made of a composition of sand, asphaltum, gravel, and cement. They gather the subsurface water and lead it into the wells from which it is taken off by mains to supply the irrigable lands.

The distributing mains which take the water from the wells are 14 inches in diameter from one well and 20 inches in diameter from the other. They enter the wells at a distance of 10 feet below the surface of the ground, the ends being bent down 20 feet into the well so as to get water from a depth 30 feet below the surface. These mains run under ground to the towns of San Bernardino and Pacoima and furnish them with water for irrigation and domestic use. The surface pipes from the wells vary between 6 and 10 inches in diameter and are under a pressure of from 10 to 300 feet.

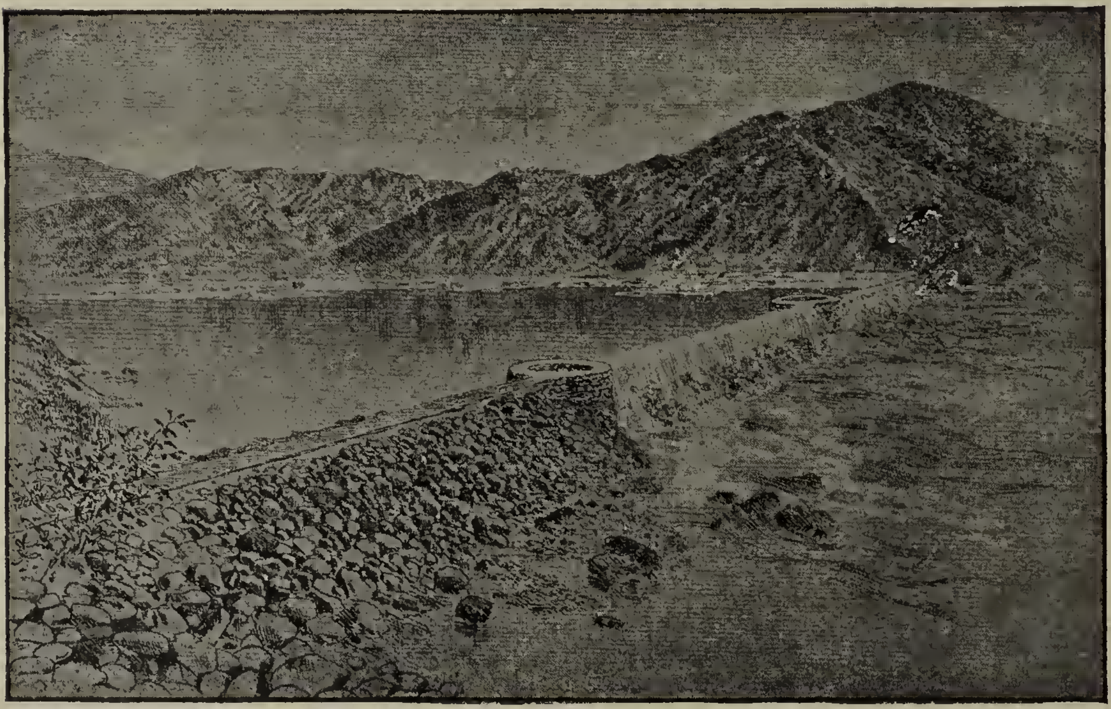


FIG. 143.—San Fernando dam.

This work was commenced in 1886 and constructed under the direction of Mr. R. M. Widney. The water supply is such that centrifugal pumps working constantly with a discharge of 80 second-feet could not reduce the level of the water in the well below 4 feet from the bottom. The inflow into the wells above 10 feet from the bottom is about 4 second-feet, while the creek above discharges as high as 200 second-feet during floods.

PUMPING.

So far the only sources of supply for irrigation described have been utilized by gravity, or natural flow. As previously, stated the percentage of irrigation practiced by means of lift—which includes the various methods of pumping—is so small as to be scarcely appreciable when compared with gravity supplies. Following the example of their predecessors and instructors, the Mexicans and Indians, the American irrigators apparently thought for many years that the only way of supplying water to their land was by means of natural flow. It is only recently that any attention has been paid to the utilization of those water supplies which are not obtainable by the aid of gravity. There is little doubt that the employment of pumps or other lift apparatus for elevating water to the lands will steadily and rapidly increase.

Among the first to employ lift irrigation in agricultural pursuits were the Chinese settlers in California. It was but natural that these should introduce such methods, as they were well accustomed to them in their own country. I have, in some cases, seen Chinese gardeners raising water from wells by means of hand and emptying it into the small furrows which led it to the vegetables. A slight advance on this method was the employment of a horse walking in a circle around a pivot and operating a lifting apparatus on a principle very similar to that of the Persian wheel of India. A still further advance has been noted in a garden in Amador county, California, where an American was irrigating a small garden patch and orchard by means of water pumped by ordinary treadmill worked by horses. But the most important development in the use of water lifted from wells was the employment of windmills for this purpose.

Windmills have been extensively used in the San Joaquin valley, California, in the neighborhood of Lathrop and Sacramento, for a number of years. There are places where the old mills are still so numerous in the fields that they average nearly one to an acre. Various kinds of windmills have been used, and constant improvements are being made in them. In some places where good supplies of water are to be found and the country is sufficiently open to insure an abundant motive power from the winds, single windmills have been seen which pump sufficient water to irrigate from 10 to 20 acres. By the use of a reservoir or a wooden tank, and allowing the mill to work constantly, enough water may always be kept on hand to supply the demands of a moderate acreage. This is perhaps the cheapest method of obtaining water, and where practicable much water may, by its use, be employed, which would otherwise be valueless. In the neighborhood previously spoken of, and from there to Stockton, California, are many windmills. The older type, and those now falling into disuse, had four vanes, each about 10 by 4 feet, and irrigated from 6 to 10 acres of berries and small fruits, though in many cases one mill does not supply more than from 1 to 3 acres.

Lifting water by means of undershot water wheels resting in the surface of flowing streams has been practiced to some extent for many years in a few isolated localities. In the foothills of California, where this class of wheel is extensively used for raising water from placer mines, they are sometimes employed to raise water to irrigate small garden patches. Such wheels have also been employed for a similar purpose in Wyoming, notably on the Green and Platte rivers. Fig. 144 shows such a wheel on the Platte river near Bridger's ferry. As will be seen, it isa plain wooden undershot wheel, and very much like an old river paddle wheel, 16 feet in diameter, the paddles being each about 10 feet in length. Just outside of the river banks is constructed a heavy crib anchor for supporting the outer axle, while in the bank is constructed a similar crib work on which the other end of the axle rests. On the outer circumference of the wheel are a row of thirty 2 gallon tin buckets. In the view shown they are simply empty tin powder cans. In other cases kerosene cans or other forms of buckets are in use. As the wheel revolves by the force of the water, these buckets are filled as they are successively submerged, and when they reach such a point that the water begins to spill out of them, this is caught in a trough placed in the right position, which empties into a small flume and leads the water off to the irrigated field. The action in the operation of these is very similar to that of the Persian wheel.

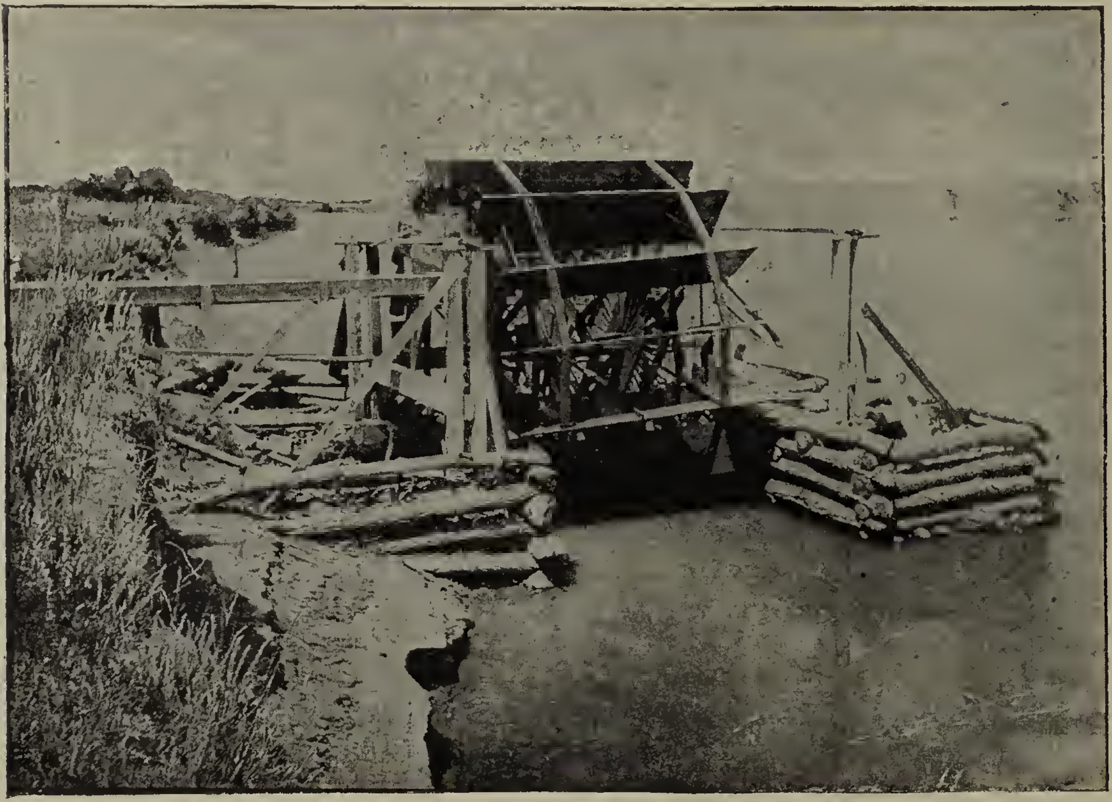


FIG. 144.—Water wheel.

In the neighborhood of Blake city at the crossing of the Green river by the Rio Grande railway are some water wheels of this form which are placed in the rude mill race in a shallow part of the river, thus insuring a good head on the wheels.[1] The supports of the wheels are well founded and the wheels themselves are from 20 to 30 feet in diameter. The axle is 5 inches in diameter and rests in a frame that can be elevated or lowered through a height of 15 feet, in order to suit the stage of water. The undershot paddles dip into the water about 2 feet, thus receiving a good propelling force. The buckets are attached to the circumference of the wheel as is ordinarily the case, but in order that the air in the bucket might escape with sufficient rapidity as the bucket strikes the water an airhole is let into the bottom, with a simple leather valve to close it. These wheels have 16 paddles each and to each a bucket is attached. These buckets are of wood and are about 6 feet in length and 4 inches square so that each bucket has a capacity of 5 gallons and the whole number of buckets will lift 80 gallons at each revolution of the wheel. Mr. Hall estimated that the wheel made two revolutions per minute and lifted 160 gallons in that time. A comparatively large percentage of this, however, was spilled in emptying it into the flume and in all it was estimated that each wheel handled 600 gallons per hour or about 2,000 cubic feet per day. One wheel in this neighborhood is said to irrigate a farm of 100 acres, though this seems hardly possible. It is claimed by the owner of some of these wheels that they cost about $50 apiece to build, while another owner expended $100 on the construction of his.

---

[1] Hall. Willis L., Unique Water Wells, Irrigation Age, vol. I, 1891, p. 186.

Another method of raising water for irrigation and one which is meeting with considerable success is that of elevators. One of the most ingenious of these is the Link Belt water elevator manufactered in Chicago. This apparatus has been successfully used on a number of farms in the west and has been generally operated by horse power, though it may be so set up that water or steam power could effect the purpose. These elevators have been made in various sizes and are given a belt speed of from 300 to 400 feet per minute. The machine consists of a link belt erected at a slight inclination from the vertical and revolving over two wheels, one pivoted a little below the level of the water surface and the other at the summit of the height to which the water is to be elevated. On this belt are a number of iron plates or vanes and when in motion the belt with these vanes, attached at intervals perhaps of 8 inches, passes up through a closed wooden boxing so that each vane on the belt acts as a lift and raises the water contained between it and the next higher vane, much as does the old chain pump used in shallow wells. This water is emptied out through a lip to a flume from which it runs to the irrigated land. With a belt speed of 300 feet the smallest of these elevators will raise about 20 cubic feet per minute to a height of 10 feet. The largest size will elevate nearly 300 cubic feet per minute or 5 second-feet of water to the same height. It was estimated by Prof. L. G. Carpenter, who carefully examined one of these elevators, that in a two-horse elevator about 25 per cent of the power was wasted, and that the apparatus lifted about one-half second-foot for a working day of 10 hours or sufficient water to irrigate from 25 to 50 acres.

The value of pumps for purposes of irrigation and the extent to which steam pumps will probably be utilized in the near future are not properly appreciated. As water becomes more scarce we shall have to search for it elsewhere than in the ordinary perennial streams. The value of steam pumping as a means of furnishing water supply will become better appreciated as its cheapness and adaptability are better understood. There are many places where water for irrigation can be pumped at comparatively small cost, and yet where the land which it will serve must otherwise remain uncultivated and useless but for the water thus obtained. The Colorado river in southern California and Arizona is in many places situated at such a depth below the surrounding country that its water must forever be permitted to run to waste if it is not pumped. The expense of diverting the water from this stream will be so great that none but a gigantic canal work is likely to be profitable and it will be many years yet before such will be built, yet the bottom lands surrounding this river are capable of producing the most valuable semitropic fruit and vegetable products. In the neighborhood of Tucson, Arizona, a water supply can be derived from wells at a comparatively shallow depth.

The cheapness of furnishing water by pumping is not fully appreciated. A high pressure pumping engine operated by Mr. H. W. Blaisdell on the Gila river in Arizona was capable of irrigating 100 acres. This pump cost $1,000 and the cost of running it was about $5 for twenty-four hours, in which time one-half second-foot of water could be raised, or say the water cost one cent per 100 cubic feet. This is equivalent to a cost of $10 per acre irrigated, which is about equal to the expense of an average gravity system, and an annual charge for running expenses of about $5 per acre, which is somewhat higher than by the gravity system.

A much better and more modern pumping plant is that operated by Mr. A. Hartt near Tucson, Arizona. This consists of a compound pumping engine capable of irrigating 600 acres at a cost of $3 a day. The first cost of this plant was $4,200. To this was added an additional cost of $5,000, because in sinking the well, which is 70 feet deep, quicksands were encountered. This was an extraordinary expense which would not ordinarily be incurred, and it would be fair to estimate the charge for sinking the well at about $1,000, making the whole plant cost something over $5,000, equal to a charge of $8·50 per acre for the plant. The daily working expenses Mr. Hartt finds to be about $3 for raising 5½ second-feet to a height of 70 feet or at a rate of about 55 cents per second-foot, equivalent to an annual charge of but 70 cents per acre. Fig. 145 shows the discharge sluice running from this pump. The stream is sufficiently large to enable the owner of the pump to irrigate 20 acres per day. It consumes but half a cord of wood in twelve hours and requires but one engineer.

The writer has made surveys and estimates for a pumping plant for the Mohave Indian reservation. The plant now being installed consists of a duplicate set of the best class of compound duplex pumping engines, each capable of raising about 1,200 gallons per minute. The height of suction is 12 feet and the water, which is pumped directly from the Colorado river, is forced to an additional height of 20 feet. It is estimated that the capacity of this plant is 1,000 acres, while its total cost erected and in working order is a little over $5,000, or about $10 per acre. It is not probable that the cost of maintenance and operation for this plant will exceed 75 cents per acre, whereas irrigation water rates on gravity plants range between $1·25 and $3 per acre.

Centrifugal pumps have been extensively used in various parts of the west. These are especially popular in California where a great many are in operation. Those in ordinary use have capacities of from 500 to 1,500 gallons per minute. One which the writer observed was pumping from a well 35 feet in depth and handled 900 gallons per minute. This is equivalent to about 100 miner's inches or 2 second-feet. It was capable of irrigating from 5 to 10 acres per day, and in a season would irrigate about 100 acres, though if handled with care its duty should be even higher than this. One man easily operates this plant at a cost of $2 per day, while the fuel costs $3·50 per day of 12 hours. This makes the cost of maintenance for an irrigating season of three

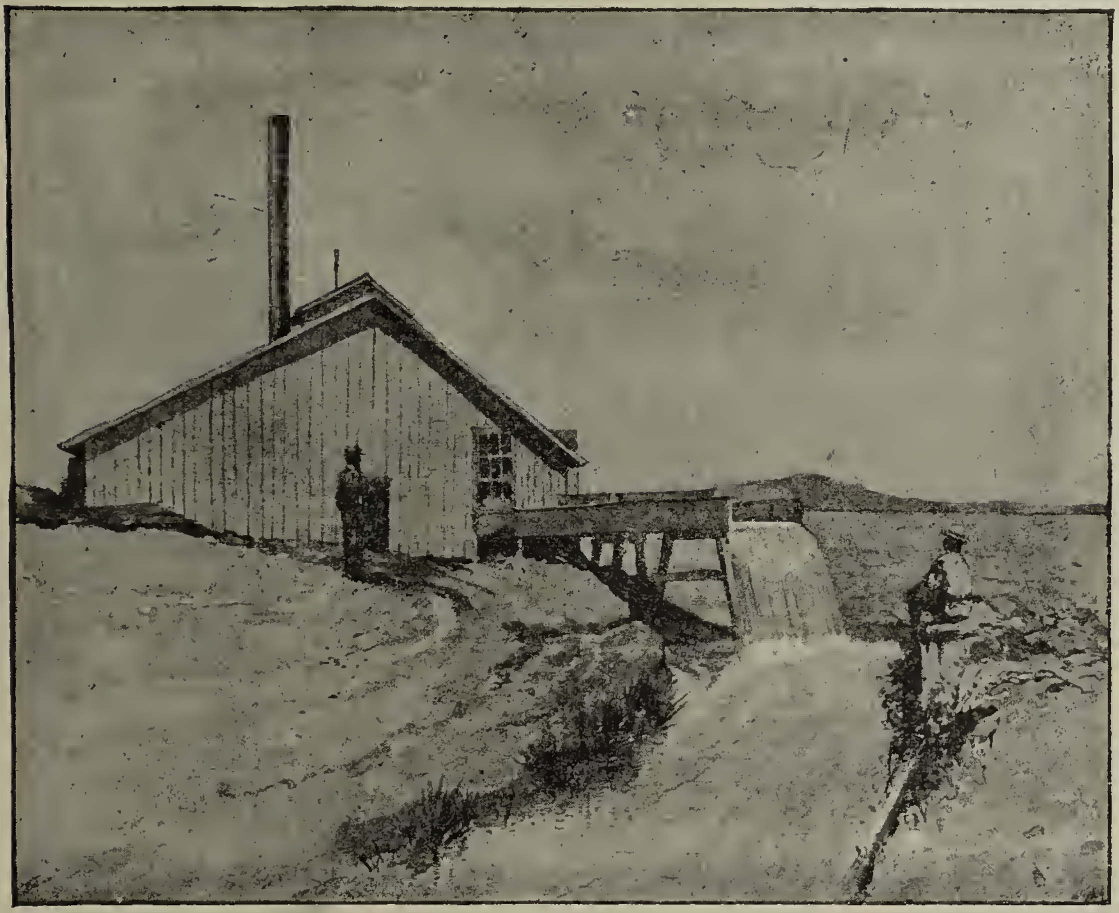


FIG. 145.—Discharge flume from steam pump, Tucson, Arizona.

months amount to about $2·50 per acre, and this in that portion of California would be a relatively low water rate. The plant cost erected, including engine, boiler and centrifugal pump, about $1,500, equivalent to a first cost of about $15 per acre.

After examination of a number of plants it appears that an ordinary centrifugal pumping plant will average from $10 to $20 per acre as a first expense according to the size of the plant, and will cost to operate from $2 to $5 per acre, also depending on the size of the plant. The larger the plant the cheaper the first cost and the cost of maintenance per acre. A first-class compound pumping engine will ordinarily cost less than this both in purchase and operation.

A special variety of pumping engines manufactured particularly for purposes of irrigation is made in Greeley, Colorado. Numbers of these are in operation in all parts of the West more especially in Colorado, Wyoming and the central West. These pumps are of a comparatively small capacity, averaging about 400 gallons a minute or about one second-foot of water each. Pumps of this character and capacity are being run on sage brush, wood, or coal, the cost differing according to the place. The price of labor is from $1 to $2 per day and the water is raised to heights as great perhaps as 20 feet and is forced only to relatively low heights rarely exceeding 40 feet. Such a pump as this will irrigate from 3 to 5 acres a day and if carefully handled from 50 to 100 acres in the season. The cost of irrigating or the water rate ranges between $3 and $5 per acre, and the first cost of the plant erected ranges between $1,000 and $2,000 or from $10 to $20 per acre as a first charge.

There are many varieties of pumps which might be used satisfactorily for irrigating crops, but the writer is inclined to favor the compound duplex pumping engine. For some purposes and with some kinds of water and a moderate lift the centrifugal pump is very satisfactory and nearly as cheap to operate. The pulsometer and vacuum pumps may serve their purpose well under certain circumstances. But for handling large volumes of water under varying conditions, the pumping engine is the cheapest in the end, both to purchase and operate, while its repairs are apt to cost less than in the case of any other variety. With such low rates per acre for the first cost, and such moderate charges for operation, it is difficult to understand why pumping by steam has not been more generally employed in irrigation.

SUBIRRIGATION.

The principles on which subirrigation is employed in applying water to crops were discussed on page 326 in this report. It consists in conducting water from distributary pipes or channels to crops to be irrigated, through a system of pipes laid a few feet below the surface. These underground pipes are of various materials, galvanized or tarred iron, earthenware, asbestine, and concrete. This system is generally employed where water is valuable and especially in southern California, where it is conducted in mains and main branches which are pipe lines.

In general these main pipe lines are constructed of wrought iron or steel sheet piping, the preferred varieties being spiral riveted pipe, converse lock joined kalamined lap-welded pipe and straight double riveted pipe. These vary from 6 to 30 inches in diameter, the thickness of the metal usually being trifling and generally ranging between No. 8 and No. 10 plate. In the case of steel pipes the metal is usually inspected with care and it must stand the proper test for elastic limit and tensile strength. For safety the minimum tensile strength should be about 60,000 pounds and the elastic limit 25,000 pounds per square inch. With straight riveted pipe the distance apart of rivets in the rows should average from 1·33 to 1·40 inches and the distance between two rows three-fourth of an inch. This wrought iron or steel pipe is invariably coated with asphaltum, the pipes being inserted in a tank of refined asphaltum fluxed with crude oil and heated nearly to burning point. In laying this pipe air valves are attached at all high places and an air stand pipe is frequently constructed at the highest point of the line, in addition to which blow-offs are placed at proper intervals and other necessary precautions taken for preserving and managing the line.

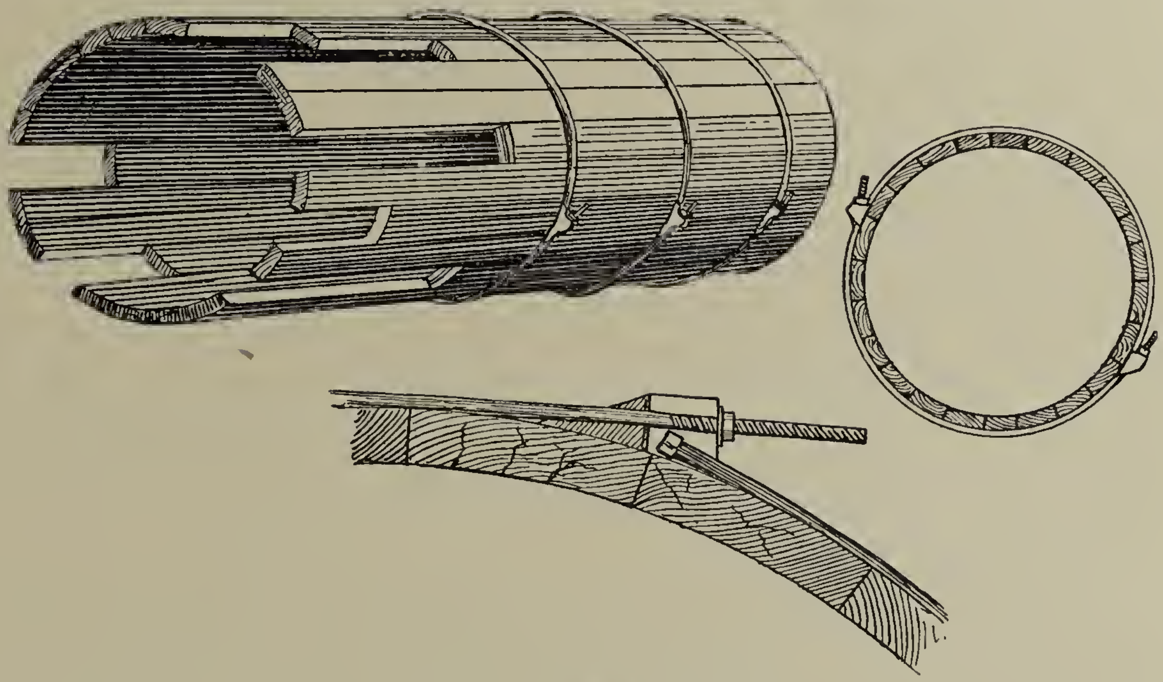


Fig. 146.—Colorado wooden pipe.

Another form of pipe for main conduit which is finding favor and coming into common use is the Colorado wooden pipe. This has been used already on several extensive works, notably in the water supply from Weber canyon for the city of Ogden, in the Denver city water supply, in one of the mains of the Perris district supply, and in an inverted siphon on the Phyllis branch of the Idaho canal. The details of construction of this pipe are well illustrated in Fig. 146, while a large piece already laid is shown on Pl. CXVIII. This pipe has been used in several dimensions, but is most popular in the larger sizes, as from 24 to 36 inches in diameter.

The walls of the pipe are formed of longitudinal staves braced together with iron or steel bands. These are shaped to cylindrical circles and on the edges to true radial lines, so that when put together they form a perfectly cylindrical pipe. The flat edges of the staves are essential to enable the empty pipe to resist the pressure from the overlying earth. To join the ends of the staves a thin metallic tongue is inserted, which, being a trifle longer than the width of the stave, cuts into the adjoining ones. This joint is very tight and easy to make. The confining bands are of round or flat iron, or steel, of from three-eighths to three-fourths inches in diameter. As shipped from the factory they are straight and provided on one end with a square head and on the other with a thread and nut. They are bent on the ground on a bending table and coated with mineral paint or asphalt varnish, and are cut about 6 inches longer than the outside circumference of the pipe, on which they are slipped loose. The ends are joined by means of a closed iron screw, which fits close upon the pipe and provides a shoulder for the head and nut. These confining bands are placed at varying distances apart according to the pressure which the pipe has to bear. The staves break joints so as to form a continuous pipe, which leaves no obstruction to the flow of water.

In Los Angeles, California, cement pipes have been used in a few cases as main irrigating ditches. These pipes are made at some central point where labor and materials are convenient, and are shipped to the site, and there they are laid on a firm foundation and the connection cemented. In one case these cement pipes were 36 inches in interior diameter. Those were made in 2-foot length and the thickness of the pipe was 3 inches with a flange 2¼ inches deep. They were made in molds of the best Portland cement and cost, when laid near or within the city limits, $2.30 per running foot laid, including the excavation of the trench, filling and all.

The distributary pipes used in subirrigation are made of various materials, generally of wrought iron or steel, terra cotta, asbestine cement or vitrified pipe. All of the so-called asbestine pipes consist of various mixtures in varying proportions of cement, gravel, lime, and sand, potash and linseed oil. Sometimes this mixture is varied by the omission of some of these or the introduction of other materials. Asphalt-concrete pipes have also been employed successfully and have the advantage over simple concrete pipes of being impervious to water. These are united by heating, so as to form a continuous pipe.

These distributing pipes are made in various dimensions according to the circumstances under which they are used and the area which each is to control. In some cases distributing pipe as small as 2 inches in diameter is employed and it ranges up to 6 inches where the mains are reached. One of the great objections to the use of pipes for subirrigation is the necessity of having holes or openings from which the water can escape, and the resultant danger to the pipe by roots growing into these openings and clogging or destroying the pipe. If muddy water is let into the pipe there is danger of clogging unless sufficient pressure can be introduced and withstood to flush them. In a few cases pipe-laying and pipe-making machinery has been used for making and laying the pipe in place, though as yet none of these machines have been satisfactory in operation. One method of letting water escape from the pipes, which seems to work most satisfactorily, consists in cutting a section several inches in length out of the continuous pipe where the plug hole should be inserted and replacing it by a square shoe placed below the gap in the pipe. A tile a little longer than the gap covers it and water escapes between the two surfaces.

With the introduction of pipes has come the necessity of devising measuring apparatus and hydrants either to distribute it or to control and measure its discharge. One of these consists in a hydrant having a cast-iron head with an oval spout through which a valve is inserted operated by a screw stem and hand wheel from above, a locking attachment being provided at the back of the valve. A more ingenious and serviceable measuring hydrant is one which is being introduced in the Alessandro tract. It consists of a 4-inch iron stand pipe resting on the 6-inch vitrified service pipes, (Fig. 147). At the summit of this measuring standpipe is a sliding gate on which is a scale so arranged that the amount of water flowing through it can be measured by simply reading the scale. A valve inside the standpipe is operated by a screw attachment and admits the proper amount of water, while it can be locked by a simple device. Outside the standpipe is a pressure gauge which shows the head of water on a measuring slot with a glass face.

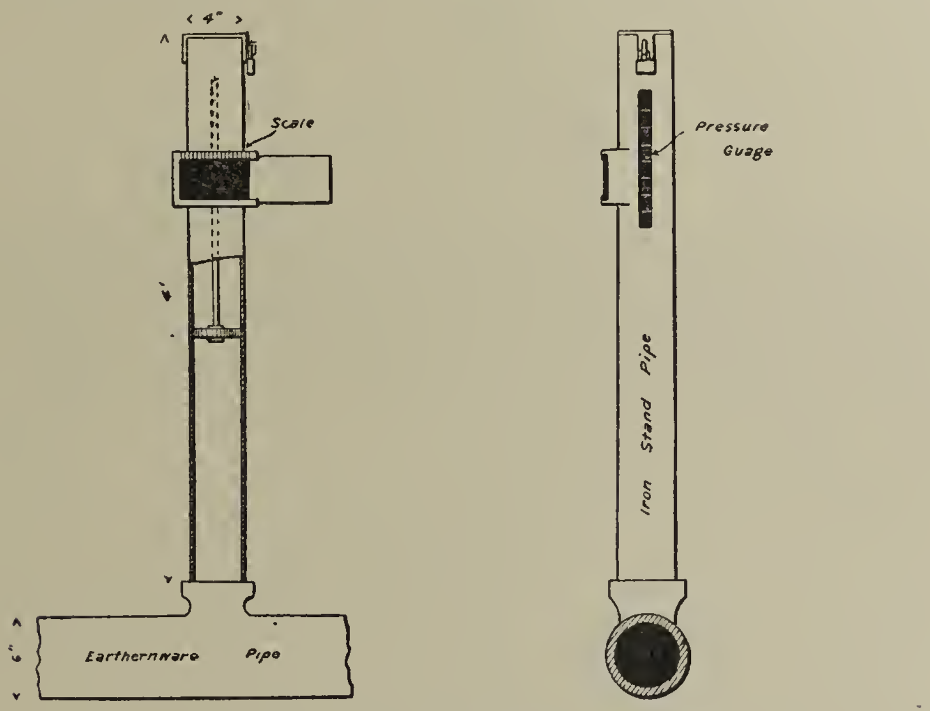


FIG. 147.—Alessandro hydrant.

TOOLS AND MACHINERY.

Nearly every American is familiar with the varieties of plows employed in ditch and canal construction. It may be well, however, to state that special ditching plows are constructed which have an unusual depth of reach and are made as right and left plows or sometimes throw the dirt in both directions having a V-shaped shear. One popular form of ditching plow is a combination of the V-scraper and sulky plow. It is practically an ordinary sulky plow with long moldboard and sideboard attached by hinged joints so that the operation of the plow and scraper are combined. This machine will form channels up to 3 feet in depth. In running the numerous furrows or ditches required in furrow irrigation or in leading the water to the fields or in other methods of irrigation, some form of plow having a V-shaped shear is generally employed, both because it saves labor and because it accomplishes its work in a more satisfactory manner than can be otherwise done.

Corrugated and ribbed rollers are largely employed in some portions of the country, especially in the neighborhood of Phœnix, Arizona, in preparing the soil for irrigation, particularly when the crop is grain or alfalfa. These consist essentially of a roller of the ordinary form on the outer surface of which are attached iron rings which project 2 or 3 inches above the surface of the roller, are 2 or 3 inches in width on the face and are placed a little further apart than this. In running this roller over the surface of a well harrowed field it leaves shallow furrows down which the water runs, thus irrigating the crop much as if it were flooded but at the same time in a more systematic manner than can be accomplished by flooding. A result similar to this is accomplished by means of a corrugated roller. This is quite like the ribbed roller just described excepting that the surface corrugations or rings are V-shaped in cross section, thus leaving a sharp V-shaped impression upon the earth which rises to a sharp summit. Such a machine as this leaves miniature furrows in the earth very similar in appearance to those left by plowing.

The most useful implement for the ditch or canal maker is the scraper. Of this there are many forms, with most of which engineers are familiar. There are two forms of the scrapers, however, employed universally throughout California which have peculiar advantages in ditch making over the ordinary road-scraper. One of these is known as the Fresno scraper and the other as the Buck scraper. The Buck scraper is essentially useful in sandy soil and with a low lift and short haul. Cheaper work has been done by this implement in light sandy soil than can be done with any other scraper. Where the soil is hard the ground must first be plowed, and if particularly hard the Buck scraper will not take hold of it or handle it with the same facility as will other forms of scrapers. Buck scrapers were used with especially good results in constructing canals in Kern and Fresno counties, especially in the former, where the soil is light and sandy. They have also been found most efficient in the lower Sacramento valley and in the neighborhood of Marysville, California, in building levees in light sandy soil. On the levees about Marysville Buck scrapers 8 feet long and 23 inches wide are employed.[1] Four horses are used to haul one of these scrapers, and the apparatus is so constructed that the driver stands on one end of the tailboard pressing the scraper into the ground by his weight. To dump the scraper the driver steps off the tailboard, when the forward pull of the horses inverts the scraper and dumps it. A very satisfactory form of Buck scraper was that employed on the construction of the upper San Joaquin irrigating canal. This scraper (Fig. 148) had an effective length of about 9 feet and the height of the face board was 22 inches. This board consisted of two planks each 2 inches in thickness and below them was an iron cutting edge reaching 7 inches farther. At either end was a cam-shaped roller 4 inches in greatest height, on which the scraper turned over. It was hinged at the back to a tailboard 3 feet 9 inches in length on which the driver stood, and held upright by an iron tie rod and operated as was the scraper just described. This scraper has performed some remarkable work on downhill excavation. The load ranges between 1 and 1·62 cubic yards, while the average daily capacity of one scraper is 128 cubic yards. The daily expense of one Buck scraper handled by four horses and one man averages about $4·65. On the Calloway and other canals in Kern valley the length of scraper now mostly employed is 6 feet and two horses are used in hauling it. The angle that the face board makes with the ground is about 28 degrees and is regulated by the attachment of the tailboard. This apparatus can be conveniently used on slopes of about 1 on 3 and is most effective in flatter slopes than this.

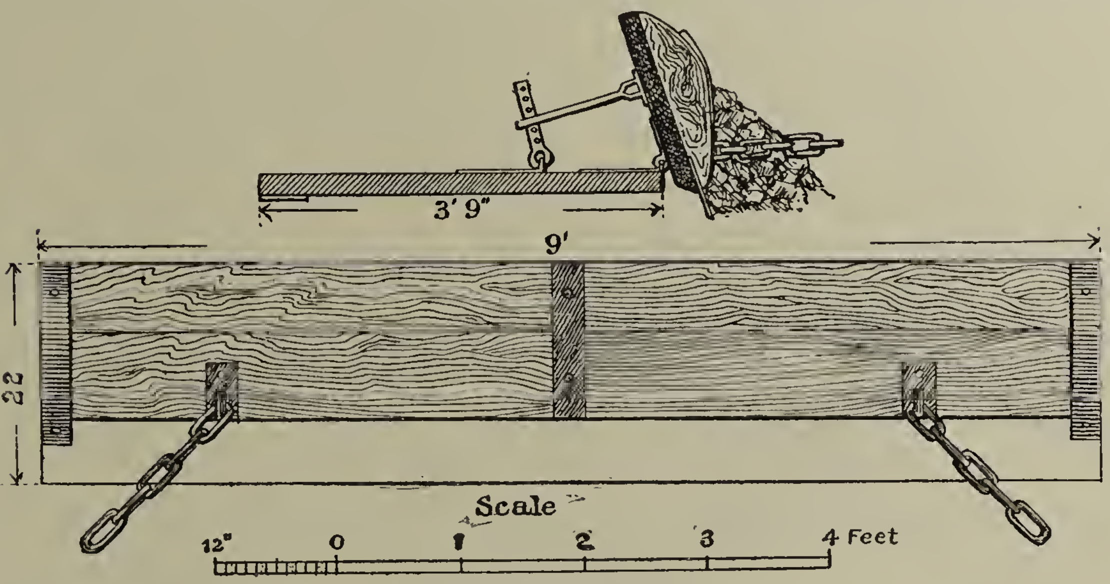


FIG. 148.—Buck scraper.

---

[1] Specht, George J. Notes on Earthwork, Technical Society of the Pacific Coast, 1885, Vol. 2, p. 145.

Various forms of wheel scrapers are employed in the west and their use finds general favor. These, like the common road-scraper, however, are so well known that they do not merit description here. A particular form of scraper with which excellent results have been obtained is the Fresno scraper. It is of sheet iron and is dumped by revolving over on a couple of slightly curved runners which raise the scraper a few inches from the level of the ground. (Fig. 149.) Fresno scrapers are most useful and satisfactory in handling tough earth such as could not be handled by a Buck scraper or might even give trouble to a common road-scraper. With this implement, which is drawn by four horses, 100 cubic yards per day can be easily moved, while its load averages one-third of a cubic yard per trip. It is most economical for heavy dirt and with long hauls and lifts.

A few combinations of scrapers and plows have been invented and employed which are most effective. In excavating the North Platte canal Mr. Sam Davidson rigged up his scrapers in batteries in such manner that they could be handled by steam traction engines. One engine was placed on either canal bank aligned directly opposite each other, and between the two was stretched a wire cable, hauled backwards and forwards by the engines. Two 12-foot spreaders or axles on wheels were attached to the cable, and to these again were fastened four scrapers, thus making two gangs of four scrapers, working one in each direction, according to which engine pulled it. This apparatus worked most successfully, the traction engines being moved forward as rapidly as the scrapers excavated the canal.

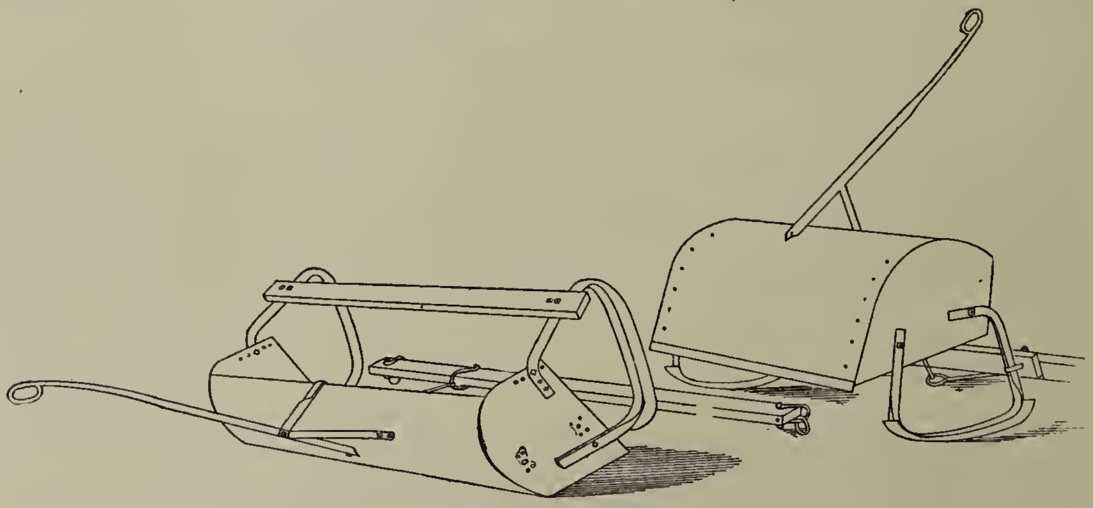
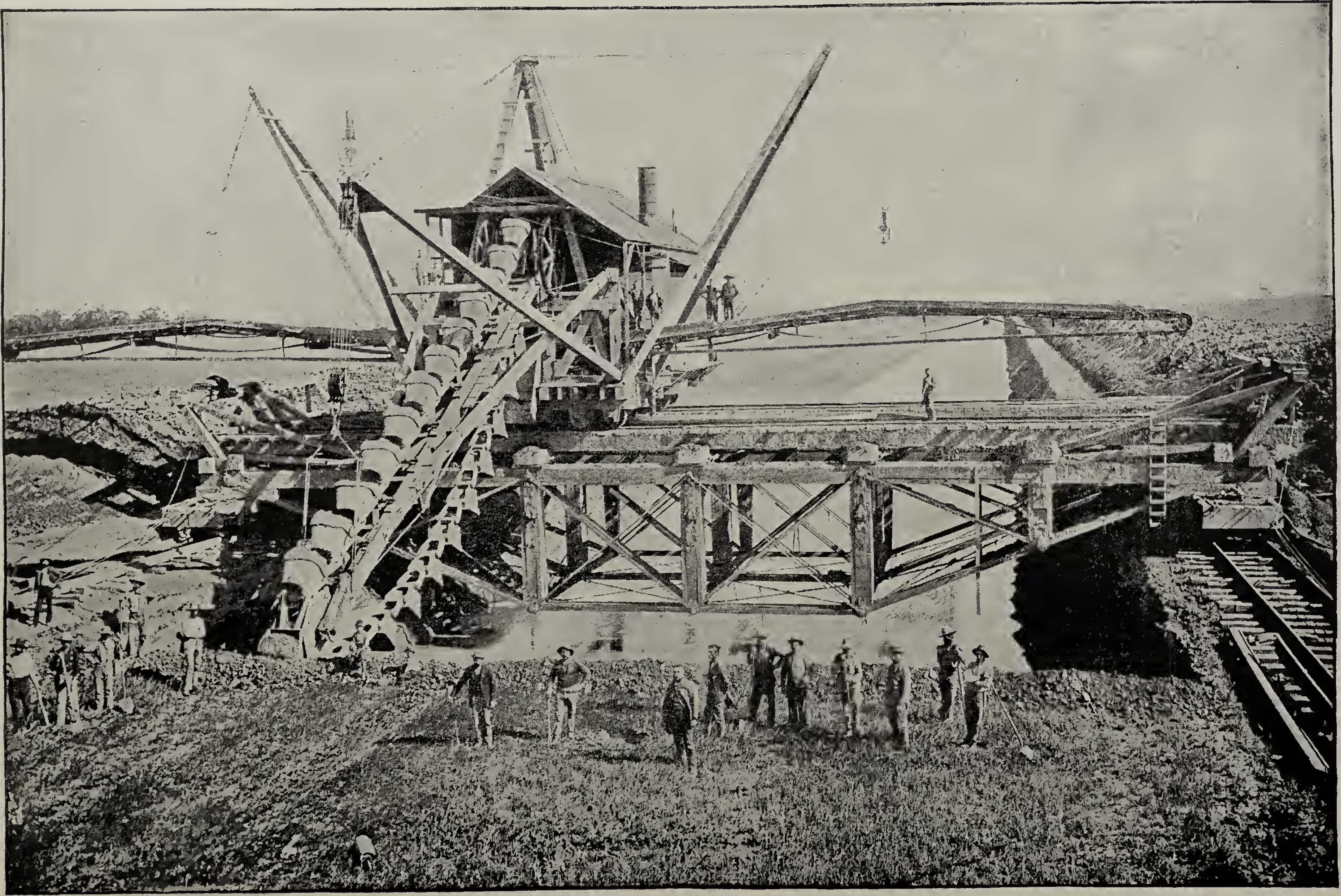


FIG. 149.—Fresno scraper.

Perhaps the most popular form of ditch machine now employed in the West wherever circumstances will permit is a ditcher and excavator (Fig. 149*a*) consisting of a gang plow suspended on wheels. An elevator or endless belt is attached to the truck above the plows in such manner that it deposits the dirt turned up by them on the banks of the canal. This machine requires from eight to twelve horses and three men to operate it. The maximum elevation which these machines are now made to lift is 10 feet, and each plow makes a furrow 12 inches



SAN FRANCISCO BRIDGE COMPANY'S EXCAVATOR.

wide and 6 inches deep. The writer has observed these machines where they attained an average capacity of 100 cubic yards per linear mile, while they averaged 1,000 cubic yards in a day's run. They can be employed not only for building canals, but they have been used successfully in Montana in building low earth embankments for storage reservoirs.

The most recent and most elaborate apparatus employed in canal construction is the great canal-excavator built by the San Francisco Bridge Company and employed in excavating the central irrigation district canal. This machine (Pl. CXLVI) consists of a bridge truss supported on wheels running on rails on either bank of the canal. This deck truss has on it a track, on which the engine house and excavating machine travels backwards and forwards across the channel. The excavator consists of a dredging arm carrying an endless chain of buckets. The material brought up by these is deposited on one of two endless belt-carriers running on booms which dump it on either spoil bank. The engineer can cause the entire machine to move forward lengthwise of the canal or can cause the excavator to move across the canal on the truss bridge or can raise or lower the excavating arm carrying the buckets and cause these to move forward and perform their work. The canal on which this machine was seen in operation—that of the Central Irrigation district—is 60 feet in bed width and had a maximum depth of 19 feet and side slopes of 1 on 1, thus making its top width nearly 100 feet. The engine employed in working this excavator was of 100 horse-power, while the total weight of the apparatus was 250 tons. The buckets weigh 1,280 pounds each and are of cast steel and there are 26 of these, which, with the chains, make their total weight 30 tons. Each bucket holds half a cubic yard and it will exca-

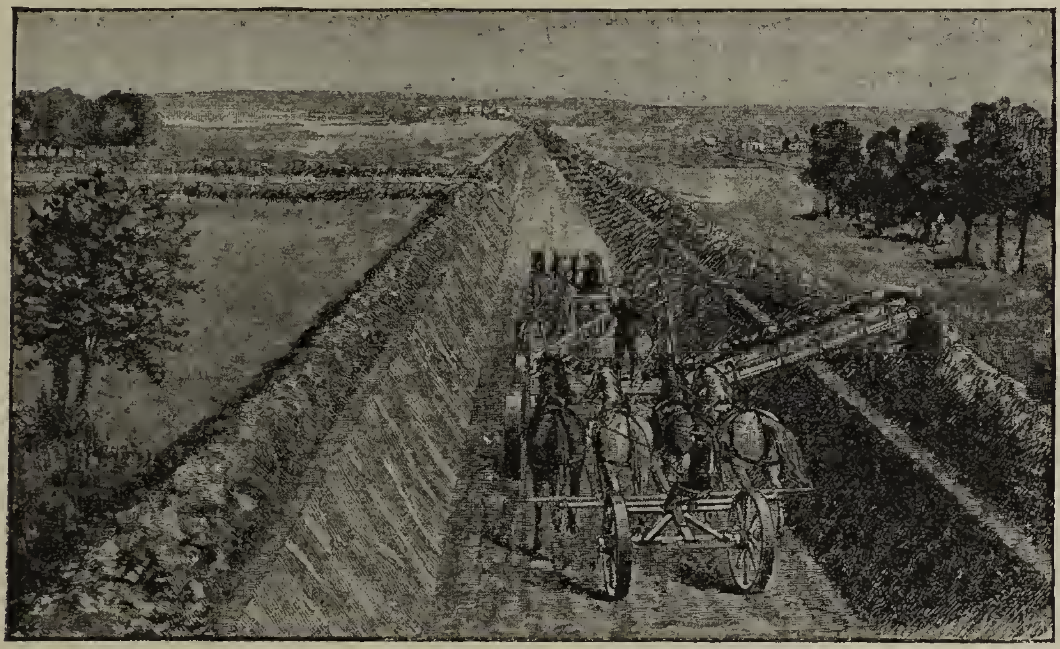


FIG. 149*a*.—New Era excavator.

vate in hardpan 3,000 cubic yards a day, though its capacity decreases with the hardness of the material and the depth of the excavation. This machine has proven most effective in material which is so hard that a pick will scarcely penetrate it an inch, and especially in excavating under water, where scrapers could not be used. In earth it has excavated from 4,000 to 5,000 cubic yards a day and in favorable material the cost of this excavation has averaged about 7 cents per cubic yard or very much less than can be accomplished by other methods.

AUTHORS' LIST.

This is not intended to be in any way a complete list of works on irrigation in the United States. It is simply a list of the works consulted in the preparation of this report and is intended as an acknowledgment to the authors for the information and assistance obtained from these works. In addition to the authors herein referred to a number of miscellaneous pamphlets and newspaper articles were consulted; the authors of these had, however, not attached their names and it became impossible to classify them in this list. A nearly complete list of authors on irrigation and an excellent bibliography for general reference were published in Part ii of the Eleventh Annual Report of the Director of the U. S. Geological Survey, printed at Washington in 1891.

Alexander, B. S. and others: Irrigation of the San Joaquin, Tulare, and Sacramento valleys, 1874. Report of the Board of Commissioners on Irrigation. House document 290; Forty-third Congress. Washington, 1874.

Allen, C. P.: Water supply of cities and villages. Transactions of Denver Society of Civil Engineers, vol. ii, 1890, p. 36.

Anderson, G. G.: Works of the Citizens' Water Company. Transactions of Denver Society of Civil Engineers, vol. ii, 1890, p. 49.

Anderson, G. G. and Titcomb, J. S.: Some aspects of irrigation. Transactions

Anderson, G. G. and Wells, W. H.: Construction and operation of large irrigation canals. Denver Society of Civil Engineers and Architects. Transactions, 1890, vol. i, p. 23.

Society of Civil Engineers and Architects. Denver, 1890, vol. i, p. 52.

Anderson, G. G.: Economical use of water. Irrigation Age, Denver, 1891, p. 45.

Aull, Charles: Dam and canal of San Quentin, California. Eleventh Annual Report of State Board of Prison Directors. Sacramento, 1890.

Bates, Walter G.: Water storage in the West. Scribner's Magazine, January, 1890, p. 1.

Black, John A.: Arizona, 143 pp., 9 tables. Phœnix, Arizona, 1890.

Blake, William Phipps: Note upon some of the results of the storage of water in Arizona (Walnut Grove dam). Transactions American Inst. Mining Engineer, 3 pp. 1889.

Bowie, A. J.: Transactions Technical Society of the Pacific Coast, 1885, vol. ii, p. 171.

Carpenter, L. G.: Report on meteorology and irrigation engineering. State Agricultural College of Colorado. Third Ann. Rept., 1890.

Carpenter, L. G.: Artesian wells of Colorado, in Bulletin No. 16. Experiment Station, State Agricultural College, July, 1891, 28 pp.

Carpenter, L. G.: Measurements and diversion of water, 45 pp., 7 illustrations, 4 tables. State Agricultural College, Bulletin 13. Second edition, 1891. Fort Collins, Colorado.

Davidson, George: Report on irrigation of the San Joaquin, Tulare, and Sacramento valleys, 1874. See Alexander, B. S., and others.

Deakin, Alfred: Royal commission on water supply. First Progress Report; Irrigation in western America, so far as it has relation to circumstances of Victoria. 175 pp. Numerous tables. Melbourne, 1885.

Denver Society of Civil Engineers: Pamphlet of convention of American Society of Civil Engineers. Denver, Colorado, 1886, p. 121.

Derry, J. D.: Victoria royal commission on water supply. Fourth Progress Report; being a report on some of the engineering features of American irrigation. Melbourne, 1885, 46 pp., 21 pl.

Finkle, F. C.: Irrigation and irrigation systems in San Bernardino County, California. Engineering News, New York, vol. 26, 1891, pp. 2, 75, 119, 147, 171.

Flynn, P. J.: Tulare irrigation district, reports on the projected works of the. 47 pp. 2 illustrations. Daily Evening Register, Tulare, California, 1890.

Flynn, P. J.: Irrigation canals and other irrigation works and flow of water in irrigation canals. San Francisco, California, 1892, 600 pp.

Follett, W. W.: Form and construction of dams and reservoirs. Denver Society of Civil Engineers and Architects. Transactions, 1890, vol. I, p. 67.

Follett, W. W.: Earthen versus masonry dams. Engineering News, Yew York, 1892, pp. 20–28.

Foote, A. D.: Automatic waste weir, 3 pp., 1 pl. Transactions American Society of Civil Engineers. Vol. XVIII, No. 78, New York, 1888.

Foote, A. D.: A water meter for irrigation, 3 pp., 1 pl. Transactions American Society of Civil Engineers. Pl. 16, No. 355, p. 134.

Foote, A. D.: Idaho, agriculture in. Irrigation Age, vol. I, Denver, 1891.

Foote, A. D.: Idaho, report on the irrigation and reclamation of certain desert lands in, and other projects connected therewith. New York, 1887, 54 pp., including 2 pls., 1 map.

Foote, A. D.: Our forest and grazing lands. Irrigation Age, vol. II, p. 240, 1891.

Graves, Walter H.: Engineer's report on the irrigation canals of Colorado. Hartford Connecticut, 1886.

Greely, Gen. A. W.: Irrigation and water storage in the arid regions. Fifty-first Congress, second session, House Ex. Doc. 287.

Greely, Gen. A. W.: National Geographic Magazine, vol. II, p. 55. See also U. S. War Dept., U. S. Signal Service.

Greene, J. S.: Fourth biennial report of the State engineer of Colorado for years 1887–'88. State printers, Denver, 1889, 1 vol., 424 pp., plates, numerous tables, 2 vols.

Greene, J. S.: Flow of water in ditches. Transactions Denver Society Civil Engineers and Architects, vol. I, p. 71, 1890, 12 pp., 3 ills.

Gregory, J. W.: Statement on irrigation before the Select Committee on Irrigation of the House of Representatives, 1890, 24 pp., U. S. Congress.

Grunsky, C. E.: The flow of artesian wells. Technical Society of the Pacific Coast. Transactions, 1884, vol. I, No. 4, p. 178.

Gully, F. A.: Arizona Agricultural Experiment Station. Bulletin No. 1, 1890. Tucson, Ariz., 4 pp.

Hall, Wm. Ham.: Report of the State engineer to the legislature of California, session of 1880, part 4, irrigation of the plains. Sacramento, 1880.

Hall, Wm. Ham.: Third progress report of the State engineer to the legislature of California, 1883, 15 pp.

Hall, Wm. Ham.: Physical data and statistics of California. Tables and memoranda of data, collected and compiled by the State engineer department of California. Sacramento, 1886, 547 pp.

Hall, Wm. Ham.: Irrigation development. History, customs, laws, and administrative systems relating to irrigation watercourses and waters in France, Italy, and Spain. Introductory to report of State engineer of California, 1886. Sacramento, 1886, 622 pp.

Hall, Wm. Ham.: Irrigation in California (southern). The field water supply and works, organization and operation in San Diego, San Bernardino, and Los Angeles counties. The second part of the report of the State engineer of California on irrigation and the irrigation question. Sacramento, 1888, 672, pp.

Hall, Wm. Ham.: Irrigation in California. National Geographic Magazine, 1889, vol. I, No. 4, pp. 277–290.

Hall, Wm. Ham.: Perris irrigation district, California. Bacon & Co., San Francisco, 1891.

Hall, Wm. Ham.: Alessandro irrigation district. Bacon & Co., San Francisco, 1891.

Hall, Wm. Ham.: Central irrigation district. Bacon & Co., San Francisco, 1891.

Hall, Willis L.: Unique water wheels. Irrigation Age. Denver, 1891, p. 186.

Hilgard, E. W.: Alkali lands, irrigation and drainage in their mutual relations. Abstract of Government report on alkali lands of India. University of California. Supt. State printing, Sacramento, California, 1886, 45 pp., 4 tables, appendix No. 7 to report for 1886.

Hilgard, E. W.: Irrigation of the arid region. In the Martindale (M. A.) prospectus of the American irrigation system. Elkhart, Ind., 1883, pp. 10–14.

Hilgard, E. W.: Report on Agricultural Experiment Station of University of California, with descriptions of the regions represented. Sacramento, 1890, 204 pp., plates and tables.

Hinton, Richard J.: Irrigation in the United States. Government Printing Office, Washington, 1890, 386 pp.

Hinton, Richard J.: Progress report on irrigation in the United States. Government Printing Office, Washington, 1891.

Maxwell, J. P.: Fifth Biennial Report State engineer of Colorado, 1889–'90. Denver, Colorado, 1891. 2 parts.

Mead, Elwood: Law of water rights. Irrigation Age, Denver, 1891, page 79.

McConoughy, O. H.; San Diego flume. Golden Era, San Diego, California, vol. 37, 1888, p. 608.

Nettleton, Edwin S.: Progress report of artesian and underflow investigations, part 2, Washington, D. C., 1891.

Nettleton, Edwin S.: Proper location of artesian wells. Progress report of artesian and underflow investigation between 97th degree west longitude and foothills of the Rocky Mountains. Part 2. Government Printing Office, Washington, 1891, 14 pp., 9 maps.

Nettleton, Edwin S.: Report State engineer of Colorado, 1883–'84, 112 pp., 25 tables. Collier and Cleveland Lith. Co., Denver, Colo., 1885.

Nettleton, Edwin S.: Third biennial report of the State engineer of Colorado, 1885–'86. Collier and Cleveland Lith. Co., Denver, 1887, 252 pp., and numerous tables, 1 map.

Newell, F. H.: Agriculture-Irrigation, Eleventh Census, Extra Bulletin No. 23.

Newell, F. H.: Hydrography, Eleventh and Twelfth Annual Reports, U. S. Geological Survey, Pt. II.

Newell, F. H.: Irrigation in Arizona, Eleventh Census, Bulletin No. 35.

Newell, F. H.: Irrigation in Idaho, Eleventh Census, Bulletin No. 157.

Newell, F. H.: Irrigation in Montana, Eleventh Census, Bulletin No. 153.

Newell, F. H.: Irrigation in Nevada, Eleventh Census, Bulletin No. 163.

Newell, F. H.: Irrigation in New Mexico, Eleventh Census, Bulletin No. 60.

Newell, F. H.: Irrigation in Utah, Eleventh Census, Bulletin No. 85.

Newell, F. H.: Irrigation in Wyoming, Eleventh Census, Bulletin No. 107.

Newell, F. H.: Irrigation work of the U. S. Geological Survey, Irrigation Age, Vol. 1, p. 10.

Newell, F. H.: Stream measurements of the U. S. Geological Survey, Transactions American Institute of Mining Engineers, 1891.

Newlands, Francis G.: An address on water storage and irrigation, Reno, Nev., 1890.

O'Mera, Patrick: Irrigation in northeast Colorado, 96 pp., 12 pls., 5 tables, 8 ills.; M. I. C. E., vol. 73, sess. 1882–'83, part 3, London.

O'Neil, Buckley: Arizona's ancient irrigators, Irrigation Age, Denver, 1891, p. 26.

Potter, W. G.: The Arkansas underflow, Irrigation Age, Denver, 1891, p. 282.

Powell, J. W.: Report on the lands of the arid region of the United States, with a more detailed account of the lands of Utah, with maps, first edition 1878, second edition 1879, 195 pp.

Powell, J. W.: Statement of J. W. Powell, Director of the U. S. Geological Survey. In report of the special committee of the United States Senate on the irrigation and reclamation of arid land, vol. 4, pp. 5–95, Washington, 1890.

Schuyler, James D.: Irrigation works in practice in Los Angeles and San Bernardino counties. Report of State engineer of California, Pt. IV, Sacramento, 1880, p. 129.

Schuyler, James D.: Works and practice of irrigation in Kern county. Report of State Engineer of California, Pt. IV, Sacramento, 1880, p. 61.

Schuyler, James D.: The construction of the Sweetwater dam. Trans. Am. Soc. C. E., vol. 19, No. 398, New York, 1888, 18 pp., 9 pls.

Scougall, H.: The construction of dams, Irrigation Age, Denver, October 1, 1891.

Scougall, H.: Construction of canals for irrigation purposes. Transactions Polytechnic Society of Utah, 1891.

Scougall, H.: Modern ideas on irrigation. Aspinall and Bell, Salt Lake City, Utah, 1891.

Sedgwick, Thomas S.: Reservoir embankments, Irrigation Age, Denver, 1891, page 162.

Specht, George J.: Notes on earthworks. Transactions Technical Society Pacific Coast, 1885, Vol. II, p. 145.

Stevenson, Charles L.: Irrigation Statistics of the Territory of Utah. Salt Lake, Utah, 1891.

Taylor, L. H.: Engineer's report to the Honey Lake Valley Land and Water Company, San Francisco, California, 1891.

Titcomb, J. S., and Anderson, G. G.: Some aspects of irrigation. Transactions Society of Civil Engineers and Architects, 1890, Vol. I, page 52.

Van Dyck, Theodore S.: Riverside mode of irrigation. Irrigation Age, Denver, 1891, pages 81–100.

Wagoner, Luther: Notes on the Walnut Grove dam. Transactions Technical Society of the Pacific Coast, 1888, Vol. V, p. 73.

Wells, W. H., and Anderson, G. G.: Construction, maintenance, and operation of large irrigation canals, Denver Society of Civil Engineers and Architects transactions, 1890, Vol. I, p. 42.

Wilson, H. M.: Pecos Valley canals. Engineering News, New York, Oct. 17, 1891.

Wilson, H. M.: American irrigation engineering. Numerous ills., 56 pp. Trans. Am. Soc. C. E., vol. 24, New York, 1891.

Wilson, H. M.: The Irrigation Problem in the West. 24 pp., 20 pls. Engineering Magazine, New York, Dec., 1892.

Wilson, H. M.: Manual of Irrigation Engineering, 29 pls., 100 figs., 350 pp. John Wiley & Sons, New York, 1892.

DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY.

ENGINEERING RESULTS OF IRRIGATION SURVEY,

BY

HERBERT M. WILSON.

CONTENTS.

Page
Introduction 357
Arkansas basin, Colorado 362
Twin lakes reservoir 365
Engineering work 364
Twin lakes dam 367
Sun river system, Montana 371
Reservoirs 374
Canal lines 383
Areas of lands reclaimable 385
Revenue 386
Truckee and Carson river systems, Nevada 387
Truckee river basin 389
Donner lake reservoir 389
Independence lake reservoir 391
Webber lake reservoir 392
Lower Truckee canals 393
Carson river basin 394
Long valley reservoir 394
Hope valley reservoir 395
California division 398
High sierra reservoirs 398
Results of surveys 400
Bear valley reservoir 401
Kennedys meadow reservoir 401
Kennedys lake reservoir 402
Lake Eleanor reservoir 402
Tuolumne meadow reservoir 403
Lake Tenaiya reservoir 404
Little Yosemite reservoir 404
Clear lake survey 405
El Paso reservoir 410
Surveys 412
Flood water storage 414
Upper site for dam 415
Design of dam 416
Estimated cost 417
Removal of the Southern Pacific R. R 419
Removal of the Santa Fe R. R 420
Pocatello canal, Idaho 422
Structures 426

ILLUSTRATIONS.

Page.
Pl. CXLVII. Topographic map, Arkansas basin .... In pocket
CXLVIII. Cottonwood reservoir site 363
CXLIX. Clear creek reservoir site 364
CL. Monument reservoir site 365
CLI. Leadville reservoir site 366
CLII. Sugarloaf reservoir site 367
CLIII. Tennessee park reservoir site 368
CLIV. Hayden reservoir site 369
CLV. Pring reservoir site 370
CLVI. Twin lakes reservoir site 371
CLVII. Sun river system 372
CLVIII. Method of survey .... In pocket
CLIX. Sun river reservoir site No. 1 374
CLX. Sun river reservoir site No. 2 375
CLXI. Sun river reservoir site No. 3 376
CLXII. Sun river reservoir site No. 4 377
CLXIII. Sun river reservoir site No. 5 378
CLXIV. Sun river reservoir site No. 6 379
CLXV. Sun river reservoir site No. 7 380
CLXVI. Sun river reservoir site No. 8 381
CLXVII. Sun river reservoir site No. 9 382
CLXVIII. Benton lake reservoir site 383
CLXIX. Willow creek and Augusta canal 384
CLXX. Donner lake reservoir site 390
CLXXI. Independence lake reservoir site 391
CLXXII. Webber lake reservoir site 392
CLXXIII. Long valley reservoir site 394
CLXXIV. Hope valley reservoir site 396
CLXXV. Kennedy's meadow and Kennedy's lake reservoir sites 400
CLXXVI. Lake Eleanor reservoir site 402
CLXXVII. Tuolumne meadow reservoir site 403
CLXXVIII. Lake Tenaiya and Bear valley reservoir sites 404
CLXXIX. Little Yosemite reservoir site 405
CLXXX. Clear lake 406
CLXXXI. El Paso reservoir site 410
CLXXXII. Pocatello canal head; site of headworks 422

ENGINEERING RESULTS OF THE IRRIGATION SURVEY.

By Herbert M. Wilson.

INTRODUCTION.

The objects and scope of the operations of the Irrigation Survey, organized in October, 1888, have been fully indicated in the irrigation reports of the tenth, eleventh, and twelfth annuals of the U. S. Geological Survey. These operations were carried on with one comprehensive plan in view, which contemplated the subdivision of the arid region into a number of hydrographic basins, in each of which the problems connected with the utilization of its water supply and lands were to be separately considered.

The three principal factors included in this plan were (1) the delineation and segregation of the irrigable lands within each basin; (2) the study of the sources of supply and the hydrography of the basin from which these lands should be watered; (3) detailed surveys indicating the methods by which the best use should be made of this water supply for the irrigation of the land.

The investigations made necessary in the study of these problems were conducted by three separate branches of the Irrigation Survey. The topographic branch, under charge of Prof. A. H. Thompson, chief topographer, was engaged in making a general topographic map of the drainage systems of the arid region, showing especially the topographic relief by means of contour lines. In addition to this, the topographic parties sought out reservoir sites and made preliminary surveys and segregations of the same, and furthermore indicated in a general way on the maps the location and situation of irrigable lands within the areas surveyed. The second branch of the Irrigation Survey consisted of a hydrographic survey, under charge of Mr. F. H. Newell, chief hydrographer. This branch prosecuted a study of the meteorology and hydrography of the various basins in so far as it related to the water supply of the basin, and it made gaugings of the discharge of the various streams within the basins to determine the volume of flow available for irrigation or for water storage. The third branch of the Irrigation Survey was the engineering branch, under charge of

Capt. C. E. Dutton, chief engineer, assisted by a corps of division engineers. At the conclusion of the field work this corps was disbanded and the work of correlating and preparing the results for publication devolved upon me. The field of the engineering branch consisted in making preliminary and final surveys for canals and water-storage projects for the utilization of water shown to be available by the hydrographic branch, and the conveyance of it to the irrigable lands.

The operations of the topographic branch extended over a large portion of the arid regions. Field parties were at work in Colorado, Wyoming, Texas, New Mexico, Montana, Idaho, Nevada, and California. Maps were made and reservoir sites surveyed and segregated chiefly in the Arkansas basin in Colorado, in the Rio Grande basin in New Mexico, on the head waters of the Yellowstone and Missouri rivers in Montana, in the Snake river basin in Idaho, and in the Carson, Truckee, and Walker river basins in Nevada and California. In all, to date, 147 reservoir sites have been located and surveyed by this division, and plats made showing the location of each, by township, range, section, and subdivision, accompanied by descriptions giving in a preliminary way the approximate contents and dimensions of the reservoirs and the dimensions of the dams and other engineering data.

The hydrographic branch operated in nearly the same localities as did the topographic branch, but covered some additional territory. Gauging stations were established and observations conducted on the Platte and Arkansas basins in Colorado and Wyoming; on the Rio Grande basin in New Mexico, the Salt and Gila basins in Arizona, the Yellowstone and Missouri river basins in Montana, the Snake river basin in Idaho, and on the Carson and Truckee basins in California and Nevada. Besides this, temporary observations were made on the various streams in central Utah and southern Idaho, notably on the Sevier, Weber, Provo, Ogden, and Bear rivers, and also on the Malheur, Owyhee, and Weiser river basins in Idaho and Oregon. In all, 53 permanent gauging stations were established, and at about 30 of these discharge observations were maintained for at least two years. In addition to these, about 150 temporary gaugings were made, distributed generally throughout the various hydrographic basins.

The operations of the engineering branch of the Irrigation Survey were carried on in about the same basins as those of the other branches. Detailed surveys for a reservoir project were made on the lower Rio Grande near El Paso; and, in addition to similar surveys, a preliminary survey for a canal was made in the Arkansas basin, Colorado, and the basin of the Sun river, one of the forks of the Missouri river in Montana. Preliminary surveys for five and detailed surveys for one canal project were made on the Snake river basin in Idaho. Preliminary surveys and locations for reservoir and canal projects were made on the Carson and Truckee river basins in Nevada. A reservoir and swamp reclamation survey was made at Clear lake, California, and some preliminary reservoir surveys were made on the headwaters of the Toulumne and Merced rivers of the Sierras of California.

It is a matter deeply to be regretted that in no case was the work of these various branches completed, owing to the discontinuance of the appropriations for conducting the work. The topographic work is still being carried on under appropriations for that purpose, and valuable preliminary information is being collected and published as rapidly as obtained. This work is complete within itself as far as it goes. A certain amount of hydrographic work, consisting chiefly of steam gaugings and the discussion and study of them is still being conducted, and this work already furnishes us with a great deal of information relative to the hydrography of the arid region and the various hydrographic basins contained therein. This work will in the course of a series of observations extending over a period of years be complete within itself so far as it goes, though many correlated studies, especially those relating to evaporation, seepage, and the duty of water and similar problems, should be investigated before the study of the hydrographic basins approaches absolute completion.

The engineering work in particular has suffered from lack of appropriations. This work was necessarily compelled to await the completion or at least the advancement of the topographic and hydrographic work before it could be conducted in an intelligent and systematic manner. It is impossible to design projects for water storage or for canals until a general knowledge of the topography of the country and the relation of the water sources to the irrigable lands has been obtained. It is still less possible to design the dimensions and details of these works until the volume of water supply and the prospective losses by seepage and evaporation have been ascertained. It would be unwise to design a reservoir, to make an estimate of its cost, to assert that its capacity would be so many acre-feet, and that it would irrigate so many acres of land, unless it were known that this reservoir could be filled every year f om the source of water supply available, and unless it were known that an adequate quantity would reach the irrigable lands before it was dissipated by absorption. The same factors must be ascertained before the cross section of a canal or its grade and duty can be determined.

All of these factors have been obtained in a preliminary and incomplete manner in five of the drainage basins studied by the topographers and hydrographers, and are here reported upon. Much more, however, must be ascertained in each of these cases before complete and intelligent projects can be definitely outlined. As far as time and the available appropriations permitted the engineering work in the following basins was prosecuted:

The study of the Arkansas basin in Colorado has most nearly approached completion, and the topographic maps of this basin have been finished. A large amount of hydrographic data has been obtained, from which the engineer is able to determine most of the factors necessary in considering the water supply. Detailed and complete surveys were made for one reservoir—that of the Twin lakes—while less complete surveys were made of eight other reservoir sites, and preliminary surveys were made by the topographic branch of 46 additional reservoir sites for the storage of water for this basin. No canal surveys were made, however, with the exception of one preliminary line run from the lower Arkansas near the Kansas state line.

On the Rio Grande basin topographic work was completed only in the immediate neighborhood of the El Paso reservoir. The larger part of the Rio Grande basin yet awaits survey by topographers. Considerable information has been obtained by the hydrographic branch and much is known of the discharge and other hydrographic data connected with the Rio Grande. The detailed survey of Lake Constance (the El Paso reservoir) was completed, and preliminary surveys were made by the topographers of 36 additional reservoir sites for the storage of water in this basin.

On the Sun river basin in Montana the topographic work awaits completion. The study of the hydrography is well advanced and furnishes nearly all the data necessary for the consideration of the engineering problems. The engineering work was more nearly completed than in any other basin and included the detailed survey of ten reservoir sites and of three canal lines for the conveyance of the stored water to the irrigable lands.

In the Snake river basin the topographic work is less advanced than elsewhere. Scarcely any topographic surveys have been made. The hydrography of the Snake river itself and of one or two of its more important branches was studied with some care, and this work was fairly well advanced. The engineering work is complete as far as it has gone, but much more remains to be done. Nearly all of the important canals which might be diverted from the Snake river below the junction of its forks were surveyed. There remains much to be done on the upper branches of the Snake and many reservoir sites will probably be discovered and surveyed.

The topographic work on the Truckee and Carson basins, like that on the Arkansas basin, has been completed. The hydrographic investigations are less advanced here, however, than elsewhere, and the same is true of the engineering surveys. Preliminary surveys were made of a number of reservoir sites and of a few canal lines. None of this engineering work, however, was of a sufficiently high grade to be considered complete as far as it was carried. In every case additional fieldwork would have to be done to complete the studies of the reservoir sites and canal lines examined. In addition to these reservoir and canal surveys made by the engineers, the topographers reported in a preliminary way on 23 reservoir sites, the lands for which were all segregated and reconnoissance surveys and recommendations made relative to the dimension and capacity of the works. These doubtless include nearly all of the reservoir sites which will be discovered in this basin.

In California practically no topographic work was done either in the mountain region or in the neighborhood of Clear lake. The same is true of the hydrographic work, so that these basins are farthest from completion of any of those examined. In the case of the mountain reservoir region preliminary surveys were made of 7 reservoir sites, but the engineering data obtained were not complete. In addition to these, 11 reservoir sites were examined and reported on in a preliminary way by the topographers, though it is probable that many others yet remain to be discovered as the topographic work advances. In the case of the Clear lake reclamation and reservoir project the engineering work was carried nearly to completion and a careful study made of the hydrography of the lake and its margin. Further engineering work will, however, be necessary before the study of this project can be considered complete.

The work of the topographic and hydrographic branches of the Irrigation Survey has already been fully reported on in detail in the eleventh and twelfth annual reports of the Geological Survey and from these the topographic and hydrographic data used in this report have been obtained. Preliminary mention only has been made of the operation of the engineering branch of the Irrigation Survey, accordingly this report contains the details of those operations as far as they were conducted and as far as it will be possible to carry the studies of the field work on the data at present in hand. The engineering work in the Sun river basin is most advanced, but it is in the Arkansas basin in particular and to a lesser degree in the Truckee and Carson basins that the most intelligent and complete discussion of all the problems connected with the irrigation in these basins is possible, owing to the more advanced condition of the topographic work. In the case of the Sun river system, the Snake river canals, the El Paso reservoir and the Clear lake surveys, only the bare engineering work with some hydrographic information can be considered because of the lack of topographic work. In the Truckee and Carson basins and the mountain surveys of California the work is incomplete in all its parts. Whereas the topographic work is completed in the former the engineering and hydrographic data are deficient, while in the latter none of the factors essential to a thorough discussion of the irrigation problems have been fully ascertained.

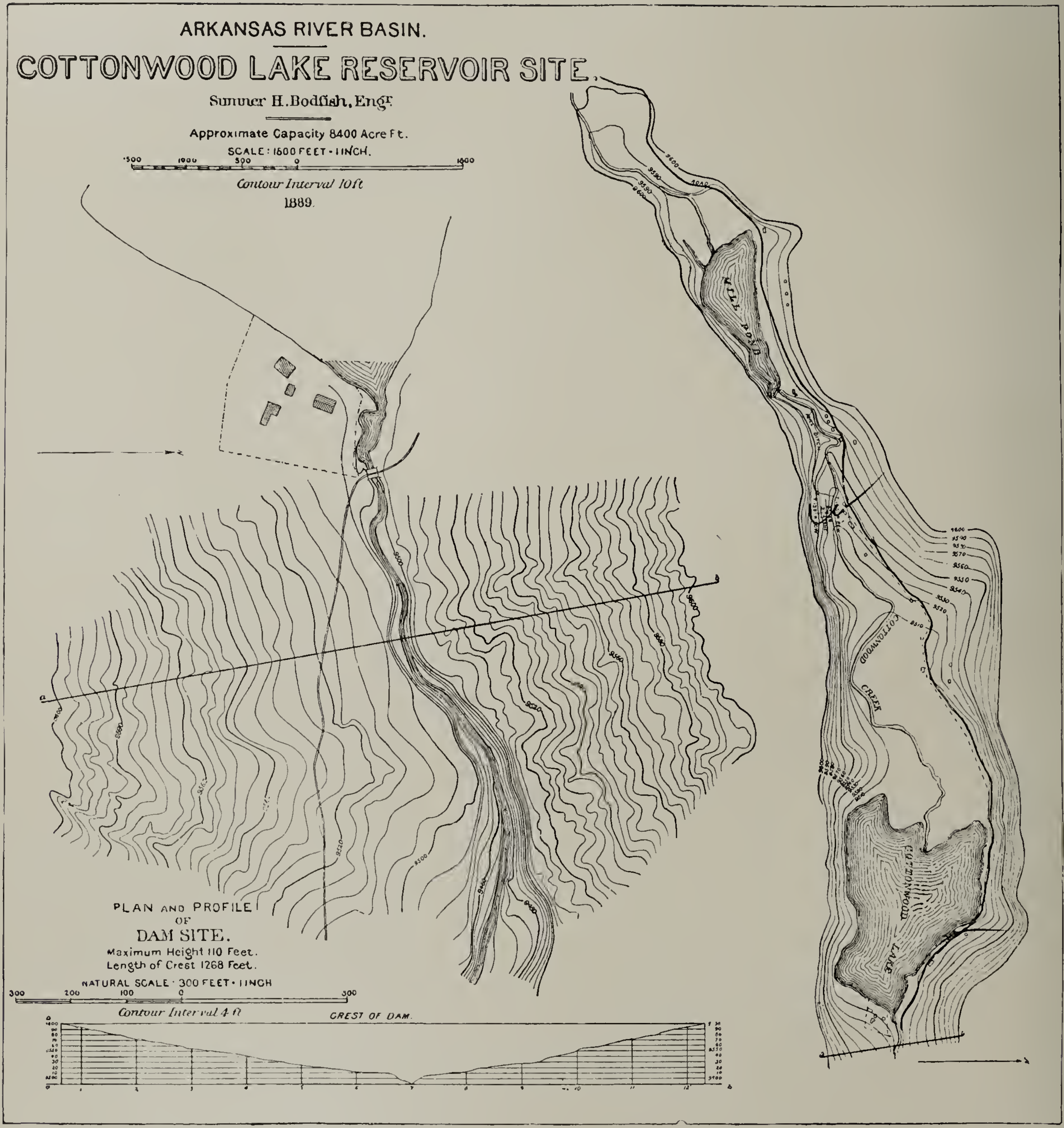
ARKANSAS BASIN, COLORADO.

The Arkansas river basin in Colorado includes three classes of topography; the high, rugged, and broken mountains of the Sawatch and Sangre de Cristo ranges, which reach heights ranging between 12,000 and 14,000 feet; the less rugged foothills, irregular and seared by canyons and marked by disconnected mesas and buttes of varying but moderate altitude; and, lastly, the great level plains or bench-land region, extending far eastward between the Platte river north and the Cimarron and Canadian rivers south. (Pl. CXLVII.)

The upper Arkansas basin above Canyon is long and narrow, and is bordered on the west by the Sawatch range and on the east by the Park range. Among the highest peaks of the former are Mount Ouray, 14,043 feet; Mount Antero, 14,245 feet; Mount Harvard, 14,375 feet; and Mounts Elbert and Massive of about the same altitude. In the Park range the highest peaks are not quite so high as those of the Sawatch range, varying between 11,000 feet at the southern end and 13,800 feet near the northern limit of the range. About 20 miles above Canyon City the river leaves its nearly north and south course, and flows to the eastward between the Sangre de Cristo and Wet mountains on the south and the Arkansas hills and Rampart or Front range on the north; breaking through this latter range, it flows through the rugged foothills in the vicinity of Canyon City and Pueblo. Here the mountains forming the rim of its catchment basin are still high. In the Sangre de Cristo range the peaks are nearly 13,000 feet. In the Rampart range is Pike's peak, which is over 14,000 feet in altitude.

Immediately eastward of Pueblo the catchment basin suddenly widens out, the river draining the plains for a distance of about 60 miles to the north and south, one of its southern branches, the Purgatoire river, rising in New Mexico. From this point eastward the topography of the country is entirely different from the mountainous region just described. The general altitude varies between 5,000 feet near Pueblo and 3,000 feet near Garden City, the country being nearly level with easy slopes into which the streams have cut deep channels.

The area of irrigable lands tributary to the Arkansas river and included within its basin is enormous. This "Great American Desert" is a desert only when deprived of water, the soil being generally productive when irrigated; in fact, the amount of land capable of being brought under cultivation is practically limited only by the amount of water which can be brought upon it. The divide between the Arkansas and South Platte rivers, which is known as the Colorado divide, may be stated in general terms to be from 1,000 to 2,000 feet higher than the rivers, the distance between which varies from 120 to 210 miles. It is safe to say that all the water available, even if the waters were all impounded for the use of irrigation, is sufficient to cultivate



ARKANSAS RIVER BASIN.

COTTONWOOD LAKE RESERVOIR SITE.

Sumner H. Bodfish, Engr.

Approximate Capacity 8400 Acre Ft.

SCALE: 1600 FEET - 1 INCH.

Contour Interval 10 ft.

1889.

PLAN AND PROFILE OF DAM SITE.

Maximum Height 110 Feet.

Length of Crest 1268 Feet.

NATURAL SCALE: 300 FEET - 1 INCH

Contour Interval 4 ft.

but a fraction of this area, and that the great bulk of the cultivation will be concentrated on the most available land, nearest the foothills and extending eastward as far as the water supply will last. It is unnecessary to make any statement of the productiveness of the soil on this plain, as its cultivation has already been practiced for many years with the most satisfactory and profitable results.

The proper manner in which to utilize the waters of the Arkansas river so as to irrigate the largest possible area of land with the water supply which can be made available by means of storage, will be to divert all of the water stored above Canyon City by means of canals heading at or near that point and lead it to the bench lands on either side of the river. The water stored below Canyon City and that which finds its way back to the river by means of seepage can again be diverted to the lands lower down. No surveys were made by the engineers of the U. S. Geological Survey with this object in view, but it is well known that such canals can be cheaply constructed, and private parties are now engaged in surveying and constructing several such high line canals.

The perennial discharge of the Arkansas river is relatively so meager that a comparatively small area of the great bench lands can be irrigated from it. Above Canyon City the drainage area of the Arkansas is 3,060 square miles. Its mean discharge during the irrigating season ranges between 600 and 5,500 second-feet. In order that a sufficient water supply for the irrigation of any considerable area of these great bench lands may be provided, the flood waters must be stored in reservoirs. According to the observations of the hydrographers of the Geological Survey,[1] the total annual discharge of the river available for storage is relatively large. At Canyon City in 1888 it ranged between 24,600 acre-feet in January and 124,355 acre-feet in June. In 1890 the maximum monthly discharge was 155,354 acre-feet in June. It probably averages 500,000 acre-feet per annum at this point.

Below Canyon City the run-off of the Arkansas basin which is available for irrigation is relatively small. Purgatoire and Huerfano creeks discharge a few second-feet each in the irrigating season, though their total flood discharge which may be stored ranges between 30,000 and 50,000 acre-feet per annum.

A great many reservoir sites have been discovered by the topographers of the Geological Survey in which these flood waters may be stored. They are of two distinct classes—the mountain reservoirs, comprising those found in the higher mountains near the head of the streams, and the plains reservoirs, consisting essentially of depressions or dry basins on the bench lands. The former are more satisfactorily situated for utilization as great storage reservoirs. Their depth compared with their area is relatively large, thus exposing the least surface to absorption. They are frequently so situated that excellent dam sites are to be found. These will store much of the flood water resulting from melting snows, which must be passed down the streams into the Arkansas and thence to some point at which main diversion canals will lead it on to the benches. The bench-lands reservoir sites are not well adapted to storing water for long periods of time. The losses of water in these from evaporation and percolation would be relatively high. They may be filled from two sources, first, by main canals from the larger streams, including the Arkansas, which will fill the reservoirs when they carry a surplus of water or when the water carried in them is not wanted for irrigation; second, by the minor streams draining the bench lands and which discharge considerable volumes in flood periods.

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation, 1890, pp. 97.

Nine reservoir sites were reported and surveyed by the engineers of the Survey in 1889 and forty-six were reported by the topographers. In area these reservoirs range from 40 acres to several square miles and are situated at elevations varying between 4,000 and 11,000 feet. These reservoirs have all been reported on in detail in the Eleventh and Twelfth Annual Reports.[1]

They may be closed by dams of various characters ranging from 15 to 150 feet in height and with capacities varying between a few acre-feet and several hundred thousand acre-feet. It is not likely that a sufficient water supply will be found to fill all of these reservoirs, though most of them can doubtless be utilized. Further and more detailed hydrographic observations will have to be made before the exact value of each of these can be determined; while detailed engineering surveys will be necessary to ascertain the practicability of constructing and utilizing them.

The accompanying topographic map to a scale of 6 miles to the inch and with contours having a vertical interval of 200 feet shows well the general topographic characteristics of the Arkansas basin. On it are represented the great mountain catchment basins, the foothills and the plains lands, also the sites of various storage reservoirs which have been discovered and for which preliminary or detailed surveys have been made. In a previous report the positions of the reservoirs surveyed were shown with relation to the land lines.[2]

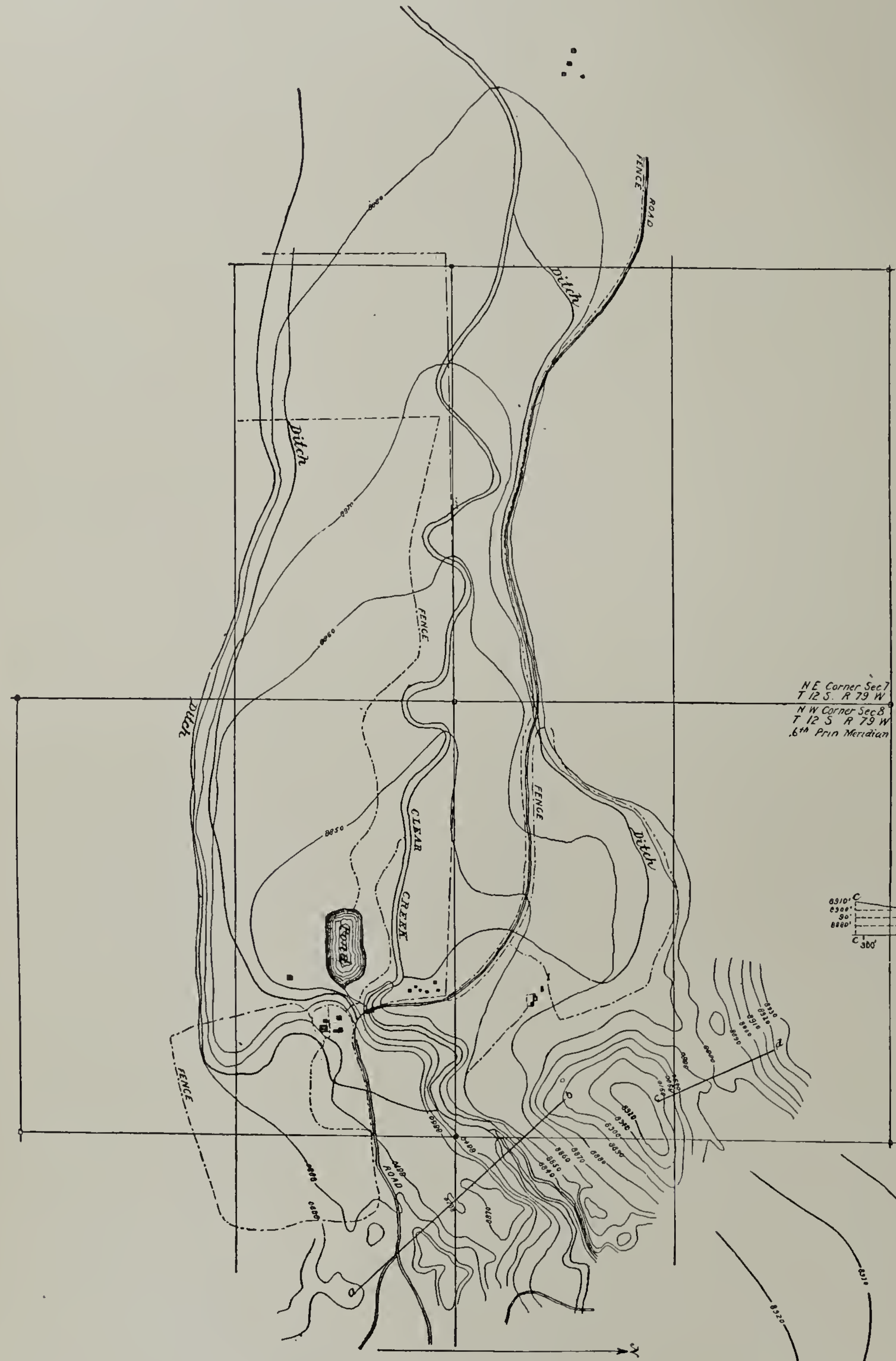
ENGINEERING WORK.

The reservoirs for which more or less detailed surveys were made in 1889 by the parties under the charge of Mr. Sumner H. Bodfish, engineer, were the following: Twin lakes reservoir site, Clear creek reservoir site, Hayden reservoir site, Sugar Loaf reservoir site, Tennessee park reservoir site, Leadville reservoir site, Cottonwood lake reservoir site, Monument reservoir site, and Pring reservoir site. Sufficient data were not obtained in the case of any of these, excepting Twin lakes site, to make any detailed calculations or estimate of the cost of con-

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation, 1890, pp. 133-144. Twelfth Ann. Rept. U. S. Geol. Survey, pt. II, Irrigation, 1891, pp. 55-125.

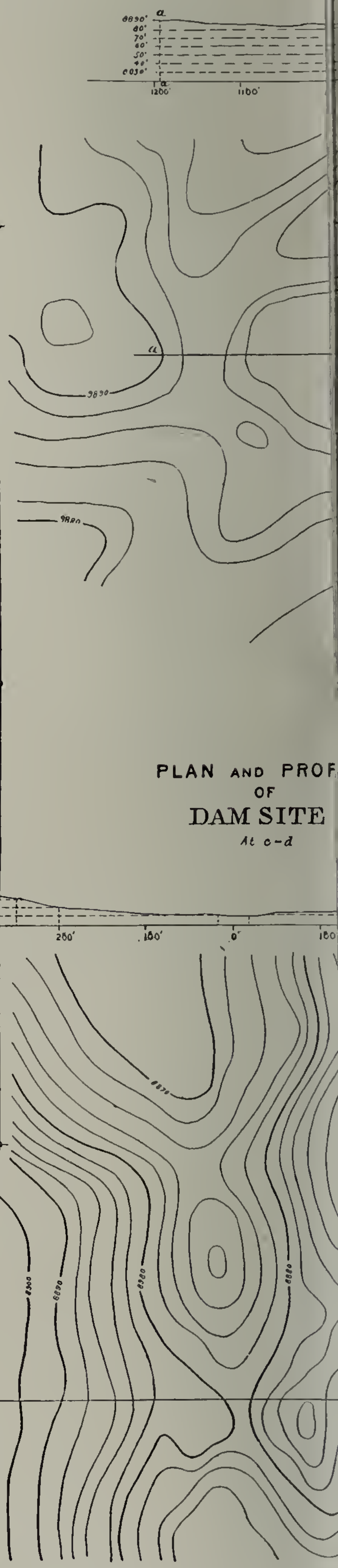
[2] Eleventh Ann. Rept. U. S. Geol. Survey, pt. II, 1889-'90, pp. 134-140.



ARKANSAS RIVER BASIN

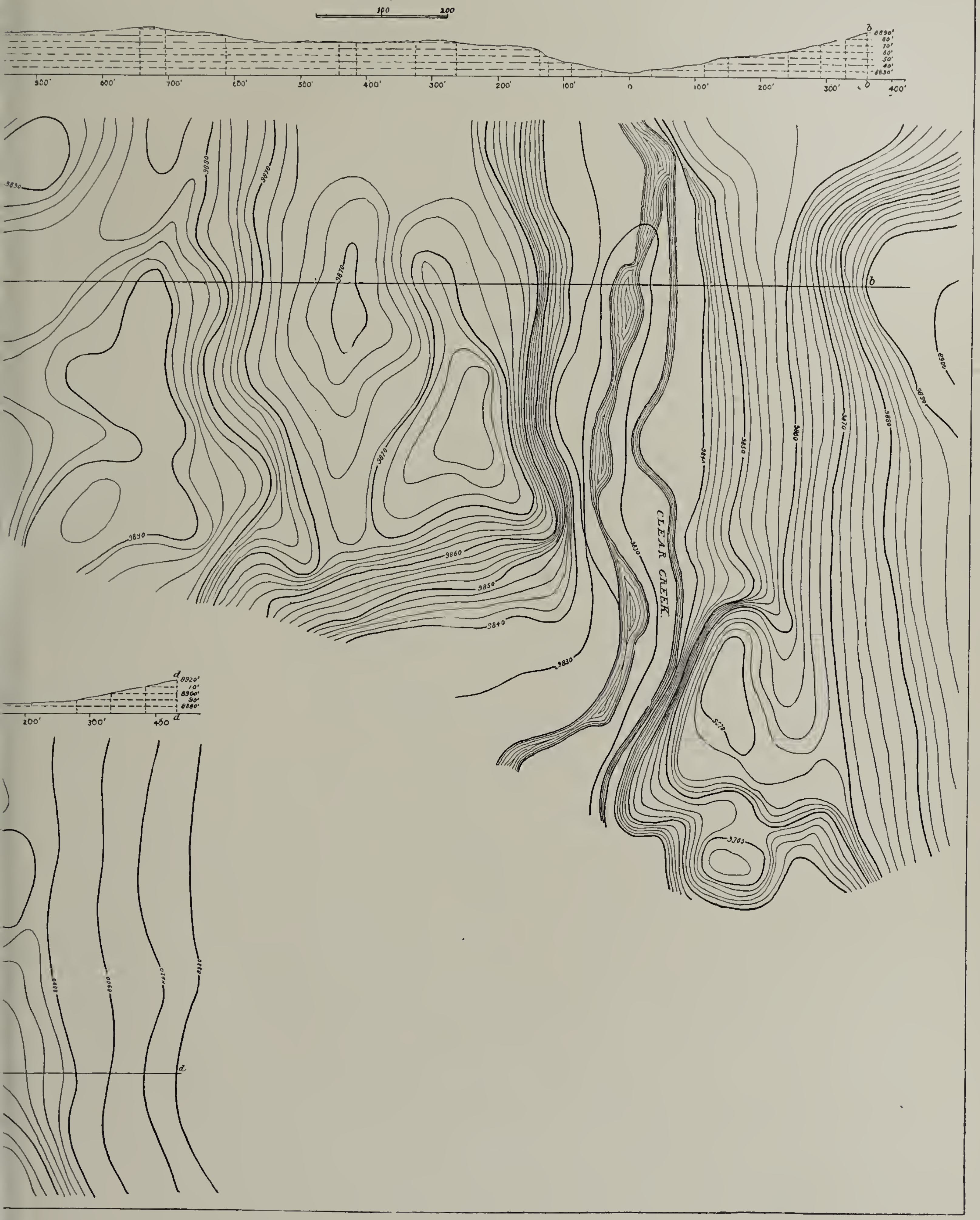
CLEAR CREEK RESERVOIR SITE

Sumner H Bodfish Engr
APPROXIMATE CAPACITY 7,000 ACRE FT



PLAN AND PROFILE OF DAM SITE

At. a – b.



ARKANSAS RIVER BASIN

MONUMENT RESERVOIR SITE.

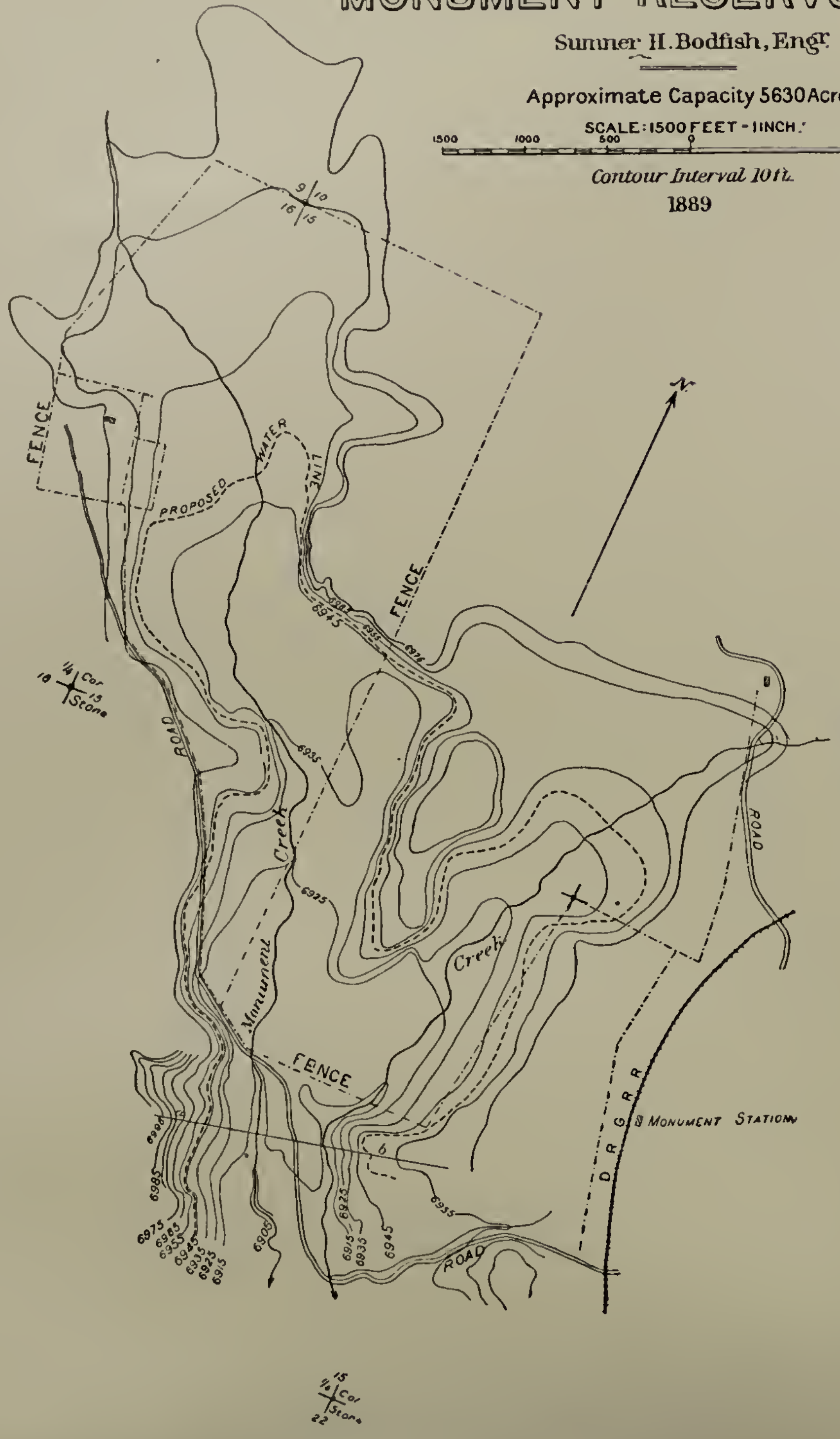
Sumner H. Bodfish, Engr.

Approximate Capacity 5630 Acre Ft.

SCALE: 1500 FEET - 1 INCH.

Contour Interval 10 ft.

1889

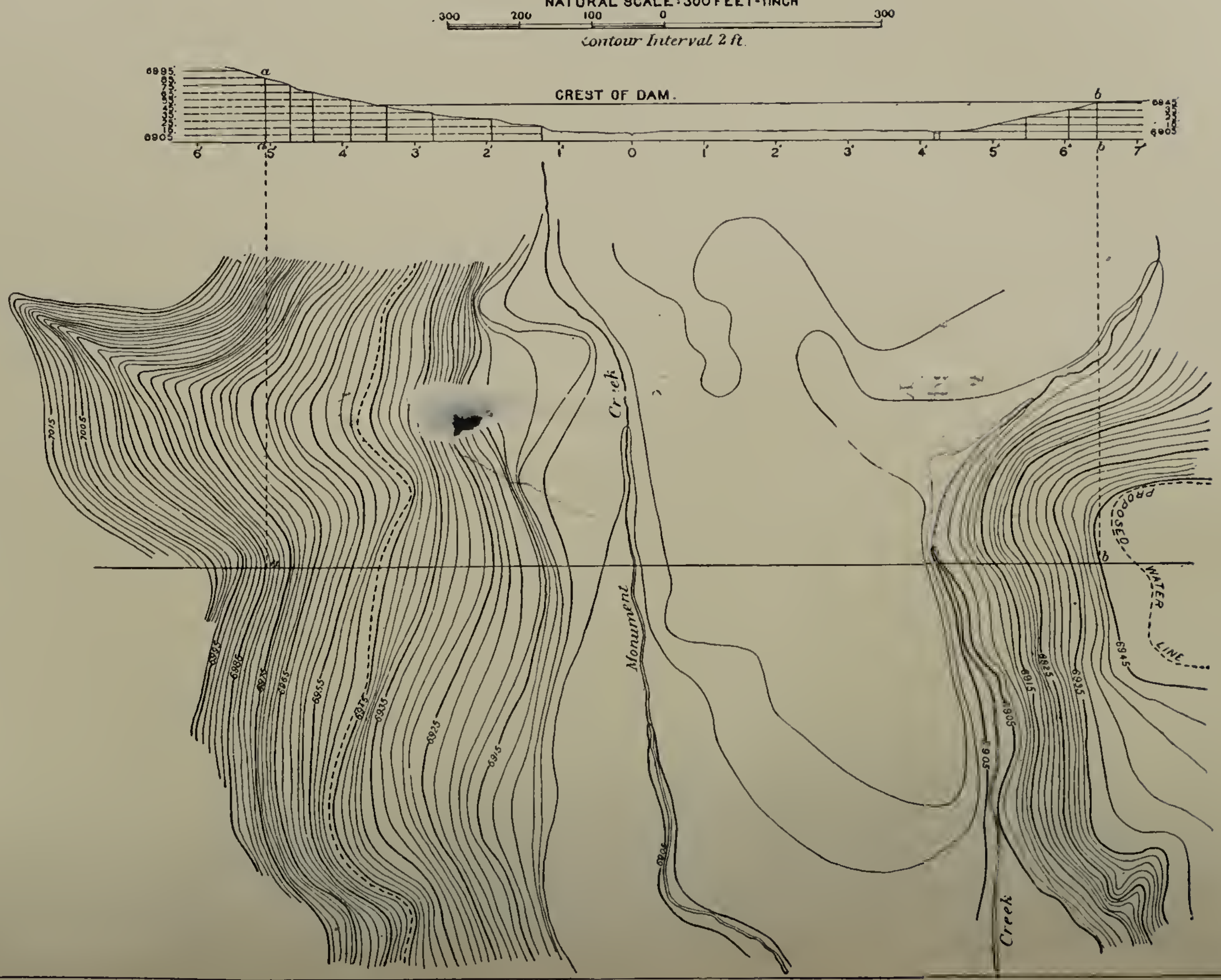


PLAN AND PROFILE OF DAM SITE

Maximum Height 47 Feet.
Length of Crest 1160 Feet.

NATURAL SCALE: 300 FEET - 1 INCH

Contour Interval 2 ft.



structing the dams; but enough surveying was done in all cases to permit maps of the reservoir sites to be plotted, and these are presented herewith.

From Plate CXLVIII it will be seen that Cottonwood lake reservoir will have an approximate capacity of 8,400 acre-feet, while it will be closed by a dam 1,268 feet in length and 110 feet in height. This is not an especially good site, as the cost per acre-foot of storage will be relatively high. Clear creek reservoir (Pl. CXLIX) will have a capacity of about 7,000 acre-feet, requiring two dams, one about 1,560 feet in length and 65 feet in height, the other about 725 feet in length and 30 feet in height. The cost per acre-foot stored for this reservoir will be less than in the last case. Monument reservoir (Pl. CL) will have a capacity of 5,630 acre-feet and will be closed by a dam 1,160 feet in length and 47 feet in height. This site is still more favorable than either of those previously mentioned. Leadville reservoir (Pl. CLI) will have a capacity of 8,875 second-feet, closed by a dam 1,162 feet in length and 105 feet in height. Sugar Loaf reservoir (Pl. CLII) will have a capacity of 45,000 acre-feet, closed by a dam 1,800 feet in length and 50 feet in height. The cost per acre-foot of storage in this reservoir will be comparatively low, this being one of the best of all the sites surveyed in Colorado. Tennessee park reservoir (Pl. CLIII) will have a capacity of 37,000 acre-feet, closed by a dam 825 feet in length and 68 feet in height. Here the cost per acre-foot will be less than in any of the preceding cases. Hayden reservoir (Pl. CLIV) will have a capacity of 45,000 acre-feet, closed by a dam 1,445 feet in length and 120 feet in height. Pring reservoir (Pl. CLV) will be closed by a dam 3,069 feet in length and 83 feet in height. The best reservoir site of all these is the Twin lakes reservoir (Pl. CLVI), which will have a capacity of 103,500 acre-feet and be closed by a dam 3,650 feet in length and 73 feet in height. In this the cost of water storage per acre-foot will be the least of any of the sites definitely surveyed.

TWIN LAKES RESERVOIR.

The glacier, which once occupied the canyon now traversed by Lake creek, brought down from the mountain sides a great amount of débris, building for the last 4 miles of its course high lateral moraines upon either side, and two terminal moraines across the valley, the lower about 1½ miles from the Arkansas river, and the other 2½ miles from the lower, making two natural dams to the present creek and thereby forming two beautiful sheets of water called Twin lakes. These lakes are situated in Lake county, Colorado, in township 11 south, range 80 west, on the sixth principal meridian. The surface of the lower and larger lake had an altitude, on July 9, 1889, of 9,194 feet, that of the upper lake 9,200 feet, and from all information available in the vicinity it is not likely that their surfaces vary more than 2 feet in altitude during the year.

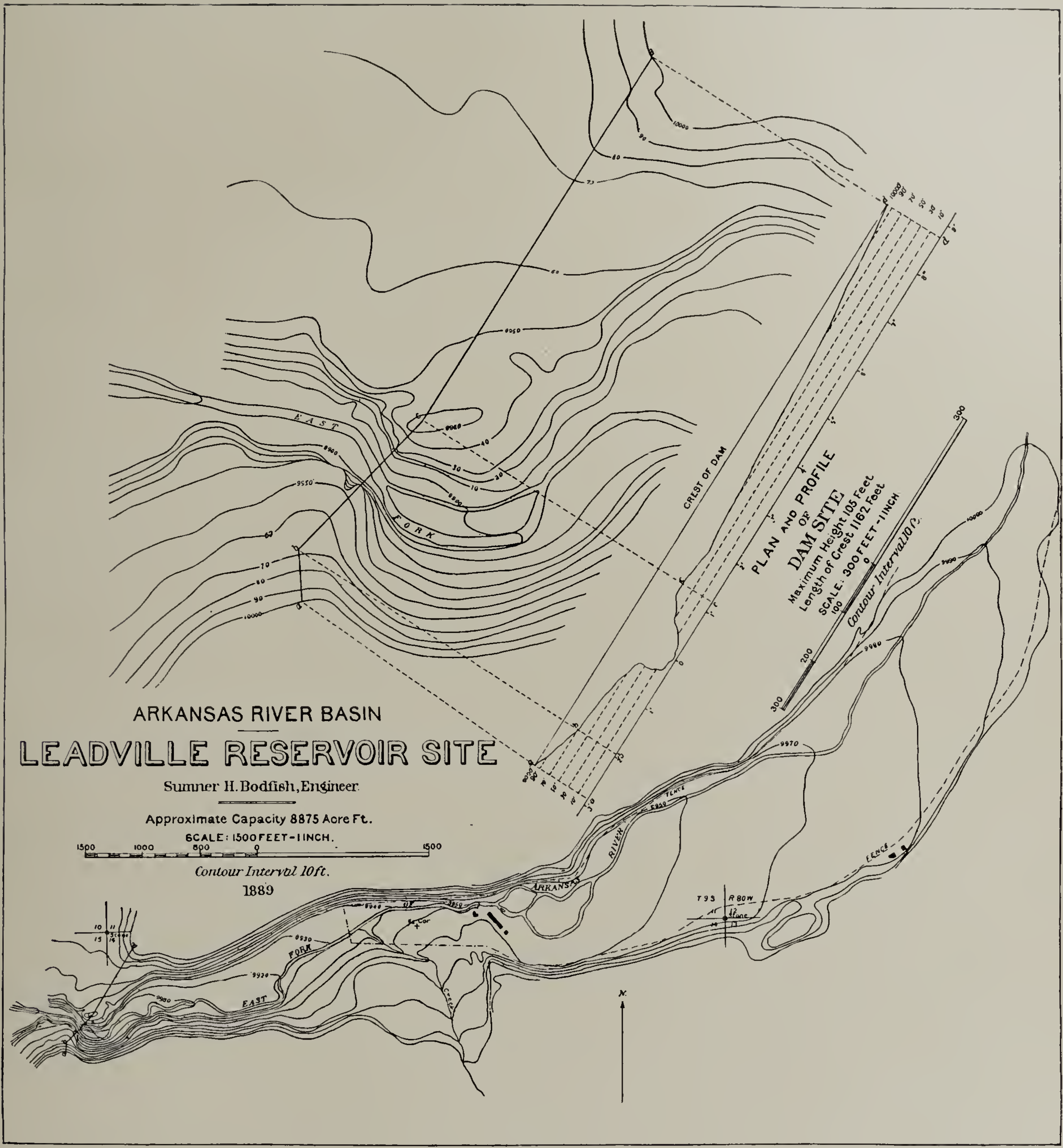
In the prosecution of the survey of these lakes Mr. Bodfish assumed a datum plane at mean sea level, and with the aid of the plane-table and level made a contour map, on a scale of 500 feet to the inch, of the lakes and adjacent country, showing 10-foot contours as high as 9,240 feet above datum, and 2-foot contours on and about the natural dam at the outlet of the lower lake. Eighty-six soundings were made of the lower and forty-four of the upper lake, from which have been constructed generalized contours of the lake bottoms with vertical intervals of 10 feet (Pl. CLVI).

At the time this survey was made it was intended to store in these lakes only the water of Lake creek at this point, and subsequent surveys were made of reservoir sites on Lake, Tennessee, and East forks of the Arkansas river, and on the river itself about 3 miles from Twin lakes, with a view of storing the water of each stream within the area of its own basin. Since the field season closed and after making a careful study of the subject, the conclusion was reached that the water of the Arkansas river could be conducted from a point near Hayden station on the Denver and Rio Grande railroad, by a canal to the lower Twin lake and store it there, thus obviating the necessity of constructing reservoirs on the Arkansas river and its tributaries.

Observations of the discharge of the Arkansas river have been carried on by the state engineer of Colorado for several years past from which the normal discharge of this stream is now well known. Early in 1889 several stations for steam-gauging observations were established by the U. S. Geological Survey among the upper tributaries of the Arkansas and were continued until August, 1890. The catchment area commanded by this canal comprises 285 square miles, which, added to that of Lake creek (102 square miles), makes a total catchment basin of 387 square miles, the water of which is available for storage in the Twin lakes reservoir From the discharges of the Lake creek, East fork, Tennessee fork, and adjacent streams, it appears that the run-off of the above catchment area will average about 15 inches in depth over the entire area of 387 square miles, or 309,600 acre-feet per annum available for storage in Twin lakes.

The crest of the dam has been assumed at 9,240 feet above datum, and the flood plane 9,232 feet. The elevation of the bottom of the lake at its outlet is 9,190 feet, and the contents of the reservoir between the contour planes of 9,190 and 9,232 is 103,500 acre-feet, assuming that the reservoir will be emptied twice a year. The expenditure of a few hundred dollars will open a ditch between the two lakes, and another from the dam to the lower lake bed, so that the old lakes can be drawn to the level of the plane of 9,180. This would increase the capacity of the reservoir to 121,800 acre-feet. The outlet should not be placed lower than 9,180, because it would necessitate considerable expense in excavating to draw off the existing lakes and also to get rid of the water below the dam.

The principal advantages to be gained by storing all of the water of



ARKANSAS RIVER BASIN

LEADVILLE RESERVOIR SITE

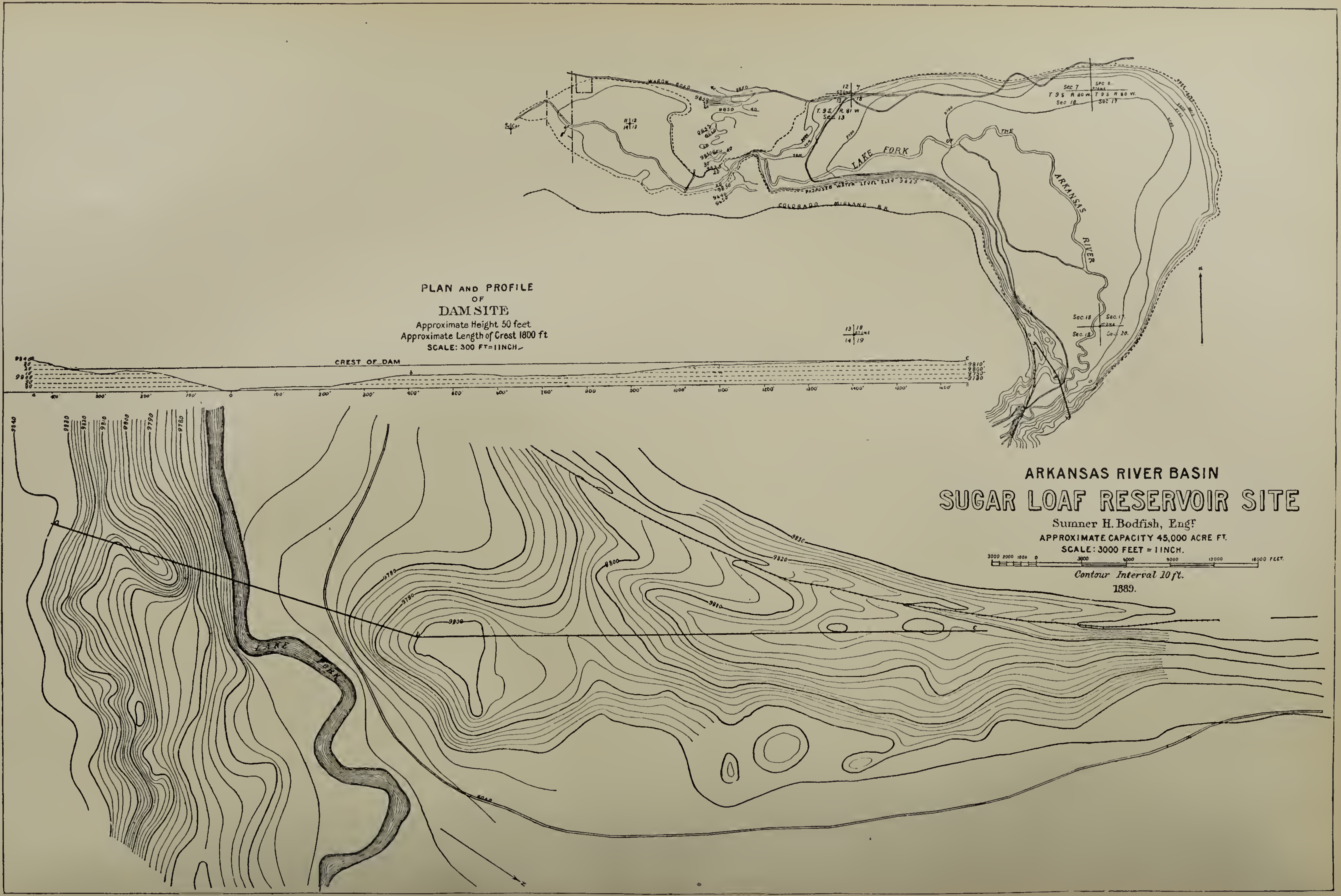
Sumner H. Bodfish, Engineer.

Approximate Capacity 8875 Acre Ft.

SCALE: 1500 FEET - 1 INCH.

Contour Interval 10ft.

1889



PLAN AND PROFILE
OF
DAM SITE
Approximate Height 50 feet
Approximate Length of Crest 1800 ft
SCALE: 300 FT=1 INCH.

ARKANSAS RIVER BASIN

SUGAR LOAF RESERVOIR SITE

Sumner H. Bodfish, Engr.
APPROXIMATE CAPACITY 45,000 ACRE FT.
SCALE: 3000 FEET = 1 INCH.
Contour Interval 10 ft.
1889.

these basins at Twin lakes rather than at two or more sites in other localities in the same basin are many. These lakes are the property of the United States; they furnish an extensive level plane upon which to store the water, and comparatively small expenditure will be incurred in purchasing land to be flooded, for the flood plane of 9,232 does not cover much of the adjacent land. The height of the dam in its highest part is no greater than would be required at other localities examined. The length of the dam is greater than at the other sites, but for three-fourths of its length it has a height above the natural surface of less than 20 feet, and for over 300 feet of its length it has no inside slope. For 200 feet only does the embankment require building to the full height of the dam.

The material available for the construction of the embankment is of excellent quality, being a gravelly soil, grading from coarse gravel to sand and sandy loam. For masonry construction there is an abundance of large granite bowlders in the immediate vicinity, and there is an abundance of growing timber of good quality within 3 miles of the dam site.

TWIN LAKES DAM.

The dam designed to close Twin lakes consists of an embankment 3,650 feet long with a maximum height of 73 feet, a top width of 28 feet, inside slope of 1 on 3, and outside slope of 1 on 1½ with berms 5 feet wide at intervals of 20 feet vertically. Provision has been made for wave action by estimating for heavy riprap covering placed upon a subcovering of stone ballast upon the inside face of the dam and by changing the slope of this face from 1 on 3 to 1 on 2 between the planes of 9232 and 9234, and to 1 on 1 between 9234 and 9236. From 9236 to 9240, the crest of the dam, the face is vertical. This allows 8 feet between the surface of the full reservoir and the crest of the dam in which to break the force of the waves, a distance not too great when it is considered that the highest wind comes from the west and northwest, driving the water upon the west face of the dam.

The entire water face is to be covered with stone ballast laid to the depth of six inches, and under and behind the upper dry rubble wall stone ballast will be laid to the depth of one foot. Upon this the riprap is to be laid about one foot in thickness, and the dry rubble wall is to be 3½ feet thick at the top, 5 feet thick at the bottom, and 8 feet high. In protecting the water face of the dam the following materials are estimated for:

Net storage capacity .... acre-feet..	114,850
5511 cubic yards of stone ballast, at $2	$11,022
6406 cubic yards of riprap, at $2.50	16,015
4790 cubic yards of dry rubble wall, at $3	14,370
Excavation of foundation of dam, 13,300 cubic yards at 20 cents	2,660
Earth dam, 168,133 cubic yards at 28 cents	47,077
Total cost of dam	91,144

The problem of discharging the water of this reservoir is one that requires the most careful consideration. The time of discharge should not exceed about forty days, and the withdrawal of 121,000 acre-feet of water within that period requires construction of the strongest character. The absence of solid rock, in bed, within the vicinity of the dam makes it necessary that the water shall be conducted through the embankment, or through the solid original ground near the embankment. By conducting the water through the embankment the gates and conduit will be placed in the gap cut by the creek in the natural dam, and the only excavation necessary will be that required for the lower half of the conduit and the foundations of the gate tower.

In order to discharge the water in about 40 days, four 48-inch pipes have been provided for, with valves, laid through the bulkhead of a masonry conduit which is 22 feet inside diameter. This conduit is designed to be 2 feet thick at the crown of the arch, and made of concrete, lined with two rings of brick masonry. The lower half is to be entirely below the old surface of the ground, and at the end near the gates, where the action of the water is the greatest, it is increased in thickness to 6 feet. The reservoir end of the conduit is to be closed with a masonry bulkhead, varying from 12½ to 17 feet in thickness, composed of a thick wall of concrete, faced inside and outside with a carefully jointed ashlar masonry wall, in no place less than 2 feet thick. It is through this bulkhead that the four 48-inch pipes are to be laid, having slide valves of the same aperture. Under the reservoir side of the bulkhead a concrete wall, to the full width of the conduit and gate tower, is extended 12 feet below the bottom of the conduit foundation, as a protection against the passage of water.

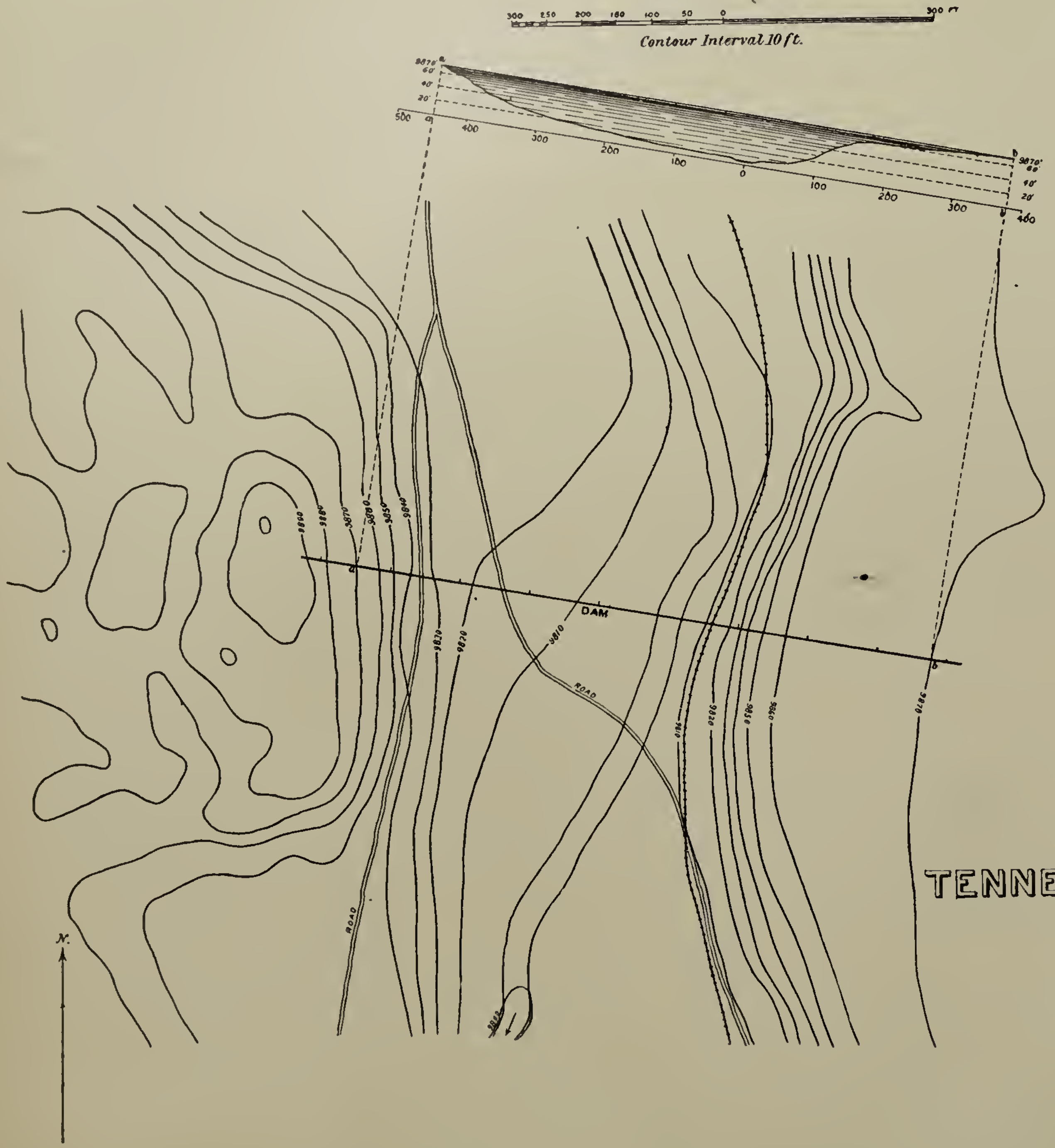
With a full reservoir the velocity of water through the 48-inch pipes will be about 44 feet per second, and the discharge through the four pipes will be 2,210 second-feet. These pipes discharge into the conduit which, with a fall of 0.17 foot per 100 feet, will carry the water with a mean velocity, due to gravity alone, of 12 feet per second, when either full or half full.

Outside of the embankment and at the lower end of the conduit provision has been made for spreading the water upon the surface of the creek bed, by extending the invert of the conduit 72 feet, at the same time widening the horizontal diameter from 22 to 100 feet. This is built of masonry with wing walls supported on the flanks by embankments having a slope of 1 on 1½, and spreads the water into a stream 100 feet wide, which will, if it is 4 feet deep and has a velocity of 5½ feet per second, carry 2,210 second-feet, equal to the discharge of the gates under a full reservoir.

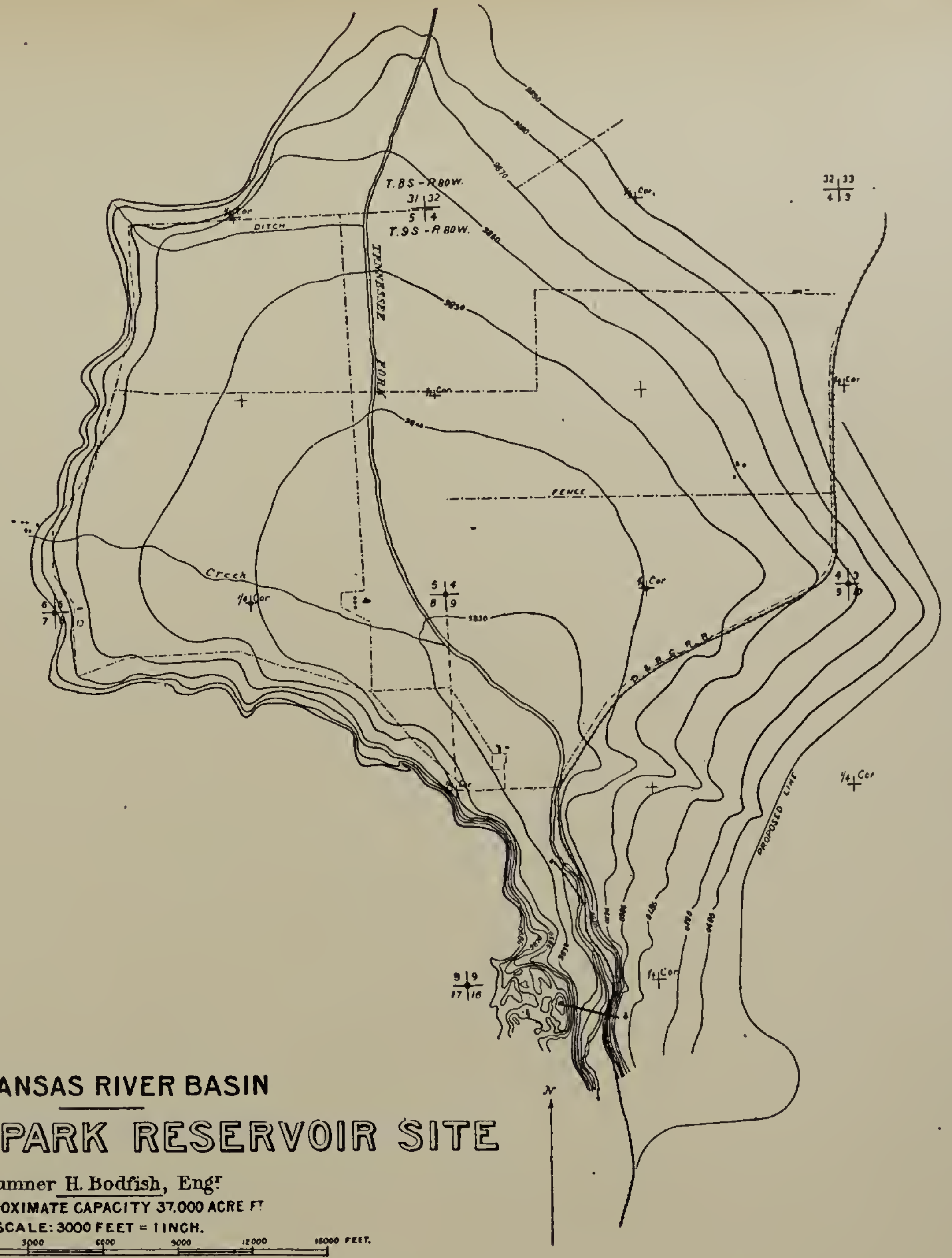
In Mr. Bodfish's opinion this form of conduit is preferable to laying a smaller metallic tube within the embankment, which is to deliver the water without the outer slope under a high velocity. If the four 48-inch pipes were continued through the embankment, the masonry nec-

PLAN AND PROFILE OF DAM SITE

Maximum Height 68 Feet.
Length of Crest 825 "
SCALE: 300 FT = 1 INCH



Contour Interval 10 ft.



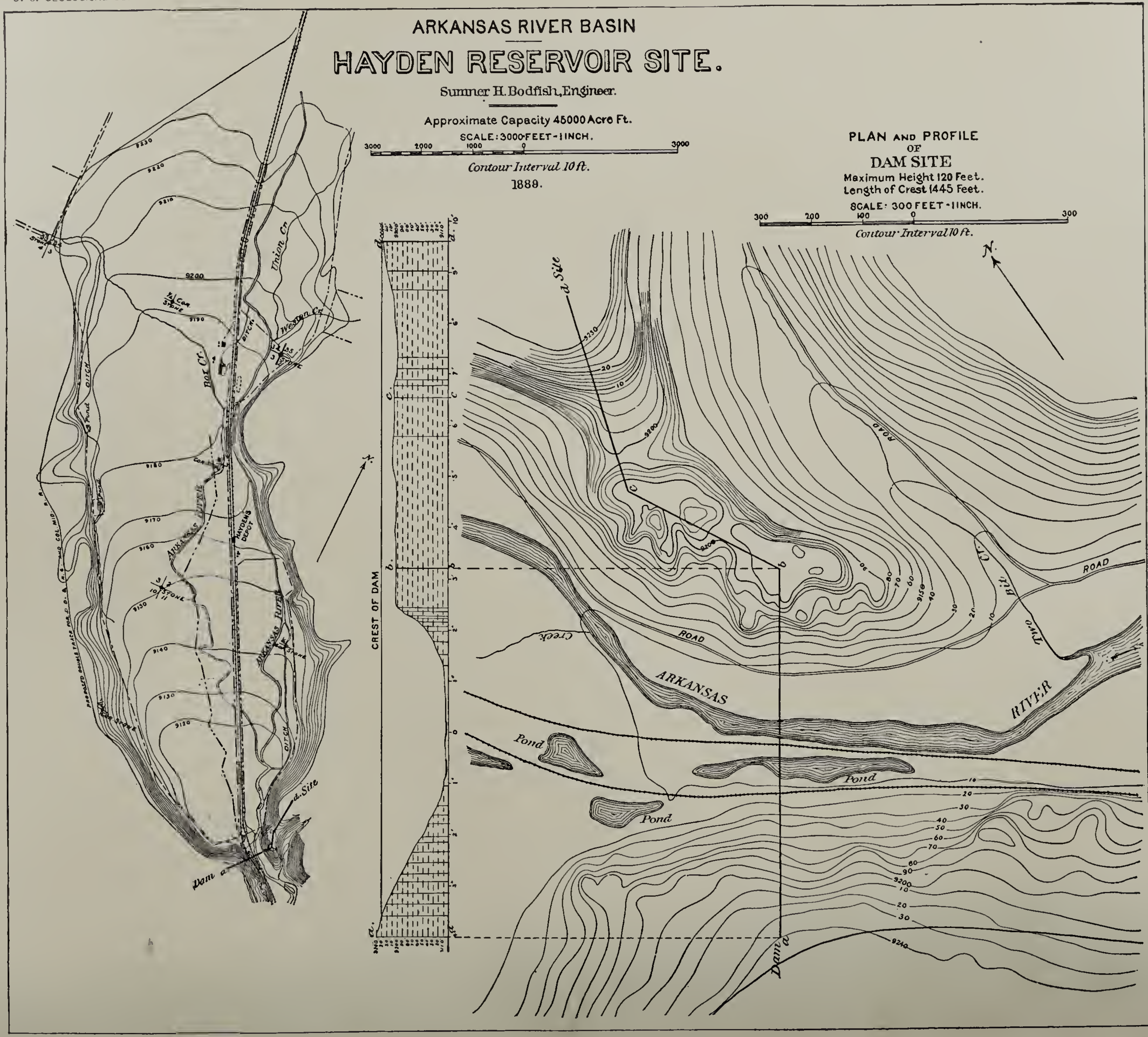
ARKANSAS RIVER BASIN

TENNESSEE PARK RESERVOIR SITE

Sumner H. Bodfish, Engr.
APPROXIMATE CAPACITY 37,000 ACRE FT.
SCALE: 3000 FEET = 1 INCH.

3000 2000 1000 0 3000 6000 9000 12000 15000 FEET.

Contour Interval 10 ft.
1889.



ARKANSAS RIVER BASIN

HAYDEN RESERVOIR SITE.

Sumner H. Bodfish, Engineer.

Approximate Capacity 45000 Acre Ft.

SCALE: 3000 FEET - 1 INCH.

Contour Interval 10 ft.

1889.

PLAN AND PROFILE OF DAM SITE

Maximum Height 120 Feet.

Length of Crest 1445 Feet.

SCALE: 300 FEET - 1 INCH.

Contour Interval 10 ft.

essary to build the chamber to contain them and to protect the creek bed below the dam would be about equal to that used in this form of construction, and the cost would be increased by an amount equal to the cost of the pipes laid.

In order to control the gates or valves, a tower is designed directly over the bulkhead of the conduit. Within this tower are four 8-inch iron pipes, water-tight, through which the valve rods pass from the valves to the house at the top of the tower. This tower is to be built of quarry-faced ashlar masonry with apertures allowing water to flow within the tower. It is to be surmounted by a brick gate-house and connected with the crest of the dam by a wooden suspension truss bridge of two spans. Upon the side of the tower toward the lake are attached tramways of angle iron to enable auxiliary gates to be lowered to stop the flow of water in any pipe the valve of which has become unmanageable. These auxiliary gates may be so loaded as to overcome the friction due to the pressure of water at the entrance to the pipe, or may travel upon rollers running upon eccentric axles.

The approach to the pipes through the lower part of the interior slope of the embankment is protected by wing-walls of uncoursed rubble masonry, and the same quality of masonry is used in the bulkhead between the conduit and tower proper; also in the wing-walls at the lower end of the conduit.

Estimates of quantities required in the construction of the conduit, wing-walls, tower, and bridges give the following results:

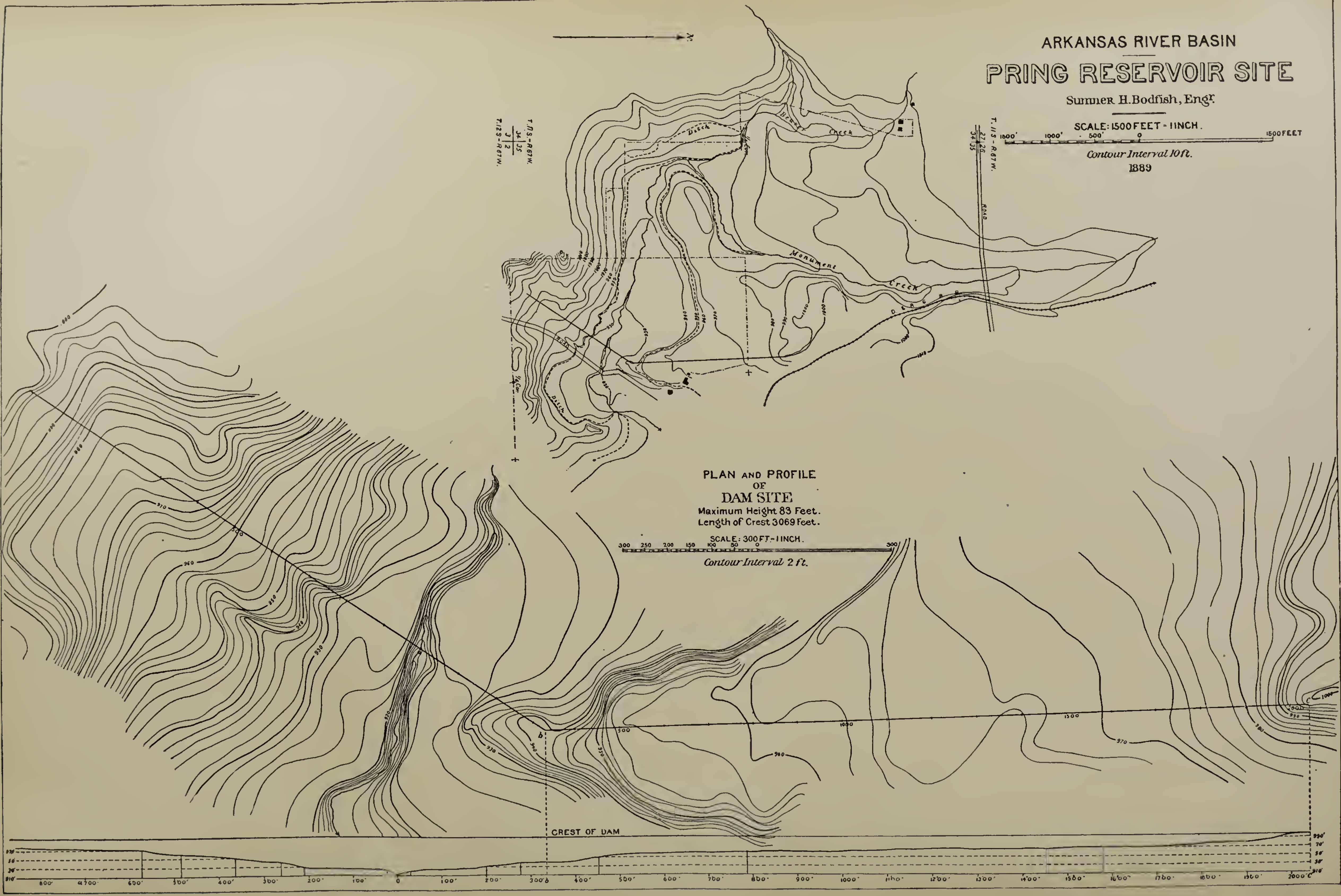
5,465 cubic yards of earth excavation, at 15 cents	$820
2,444 cubic yards of concrete, at $6·50	15,886
4 48-inch iron valves, at $1,500	6,000
4 auxiliary gates, at $50	200
518 cubic yards of brick masonry, at $15	7,770
850 cubic yards of rubble masonry, at $7	5,950
640 cubic yards of cut stone masonry, at $16	10,240
115 cubic yards of coping, at $10	1,150
76,520 pounds of iron pipe, girders, etc., at 7 cents	5,356
12.8 M. B. M. lumber, at $30	384
Incidental	150
Cost of conduit, etc	53,906
Cost of dam	91,144
Total cost of works	145,050
Plus 10 per cent for contingencies	159,555
Cost per acre-foot stored	1·40

To the above must be added the cost of condemning the land to be flooded by the proposed reservoir, in all 2,000 acres at $10 amounting to $20,000. Add to this $15,000 for improvements and the total cost of the land will be $35,000.

It is believed that the canal required to lead the waters from the Arkansas river at Hayden to fill Twin lakes will not be over 3½ miles long, and estimating it at $8,000 per mile its cost will be $28,000, which added to the above makes the grand total cost about $222,500.

In the above no provision is made for a waste-way, as it is believed that the volume of water in the reservoir can at all times be so regulated by means of the discharge sluices as to make the provision of a waste-way unnecessary. This is especially true in view of the large surface area of the full reservoir, 3,475 acres. The total storage capacity of the reservoir is 121,800 acre-feet, from which subtract 6,950 acre-feet, equivalent to a loss of 2 feet from the surface by evaporation and percolation during the early spring months of storage. The remaining 114,850 acre-feet of net storage water will suffer a loss, say of 30 per cent, in conveying it to the irrigable lands, leaving 80,400 acre-feet for application to the land, which at one and one-half acre feet per acre irrigated will bring under cultivation 53,600 acres.

At the rates now charged in Colorado a water right in perpetuity is worth about $10 per acre subject to a further annual tax of $2 per acre irrigated. Without deducting the revenue from the sale of water rights, the annual income from 53,600 acres irrigated at $2 per acre will return nearly 50 per cent per annum on the original outlay of $222,500 after deducting $15,000 for maintenance and repairs.



ARKANSAS RIVER BASIN

PRING RESERVOIR SITE

Sumner H. Bodfish, Engr.

SCALE: 1500 FEET - 1 INCH.

Contour Interval 10 ft.

1889

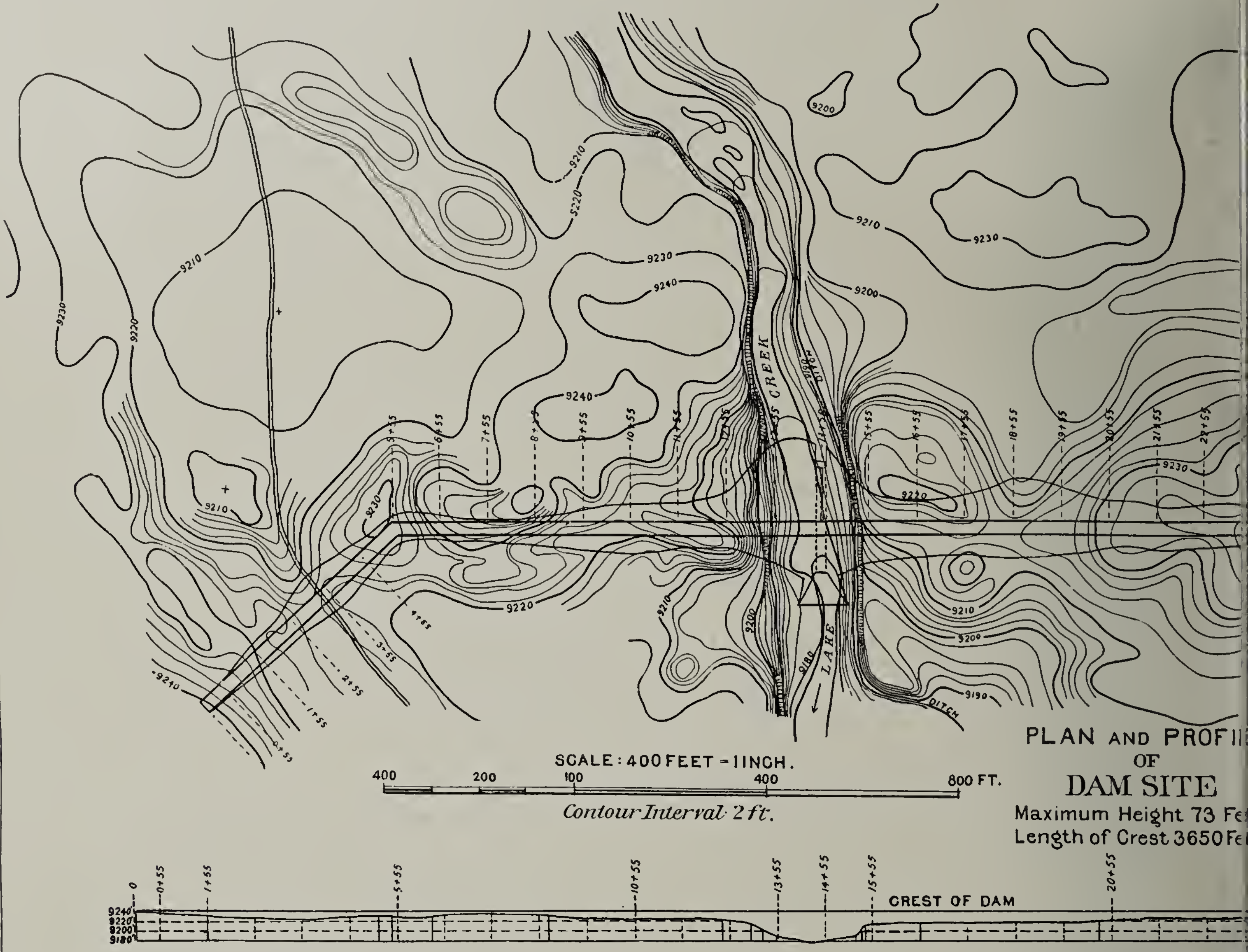
PLAN AND PROFILE OF DAM SITE

Maximum Height 83 Feet.

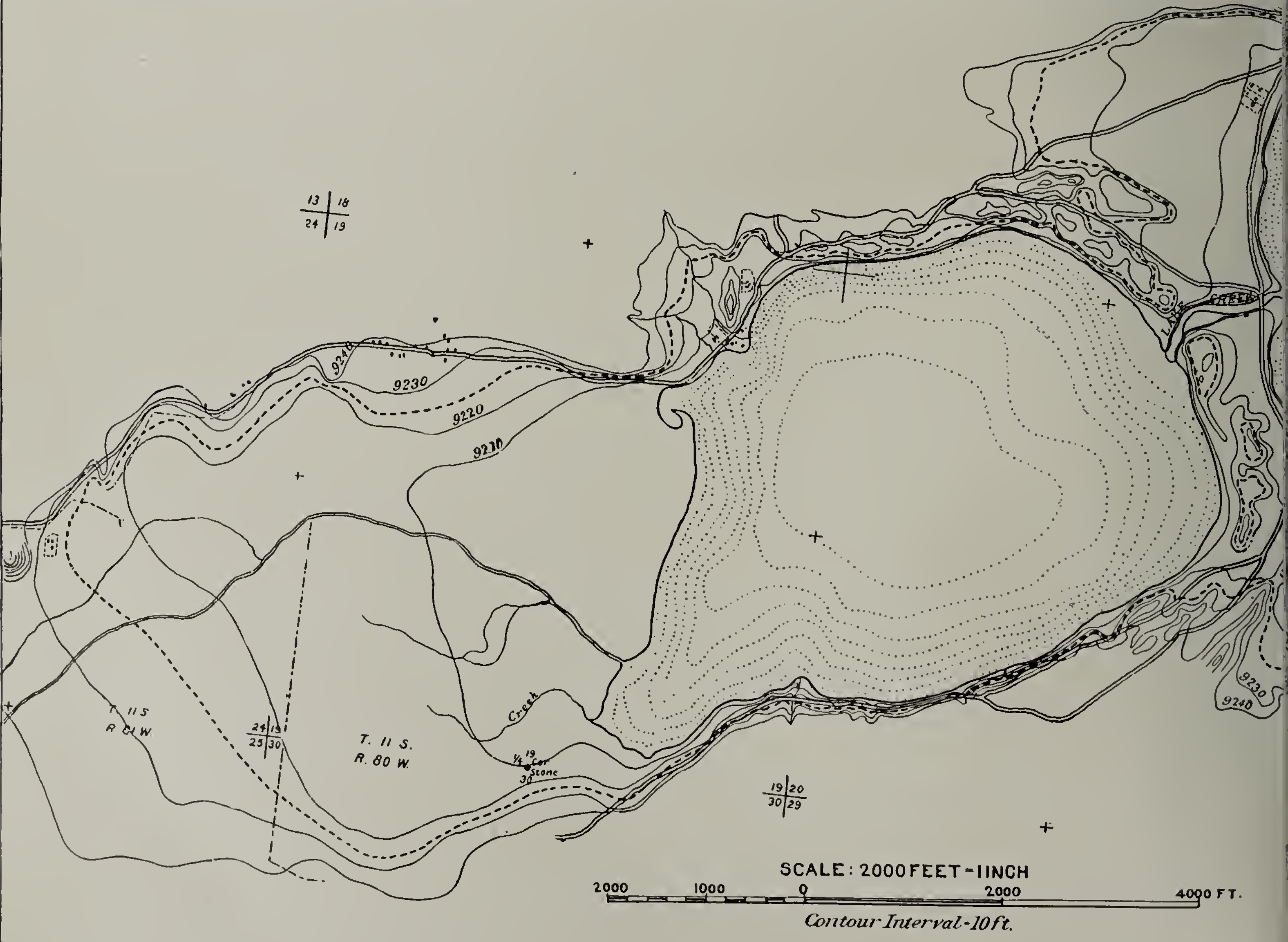
Length of Crest 3069 Feet.

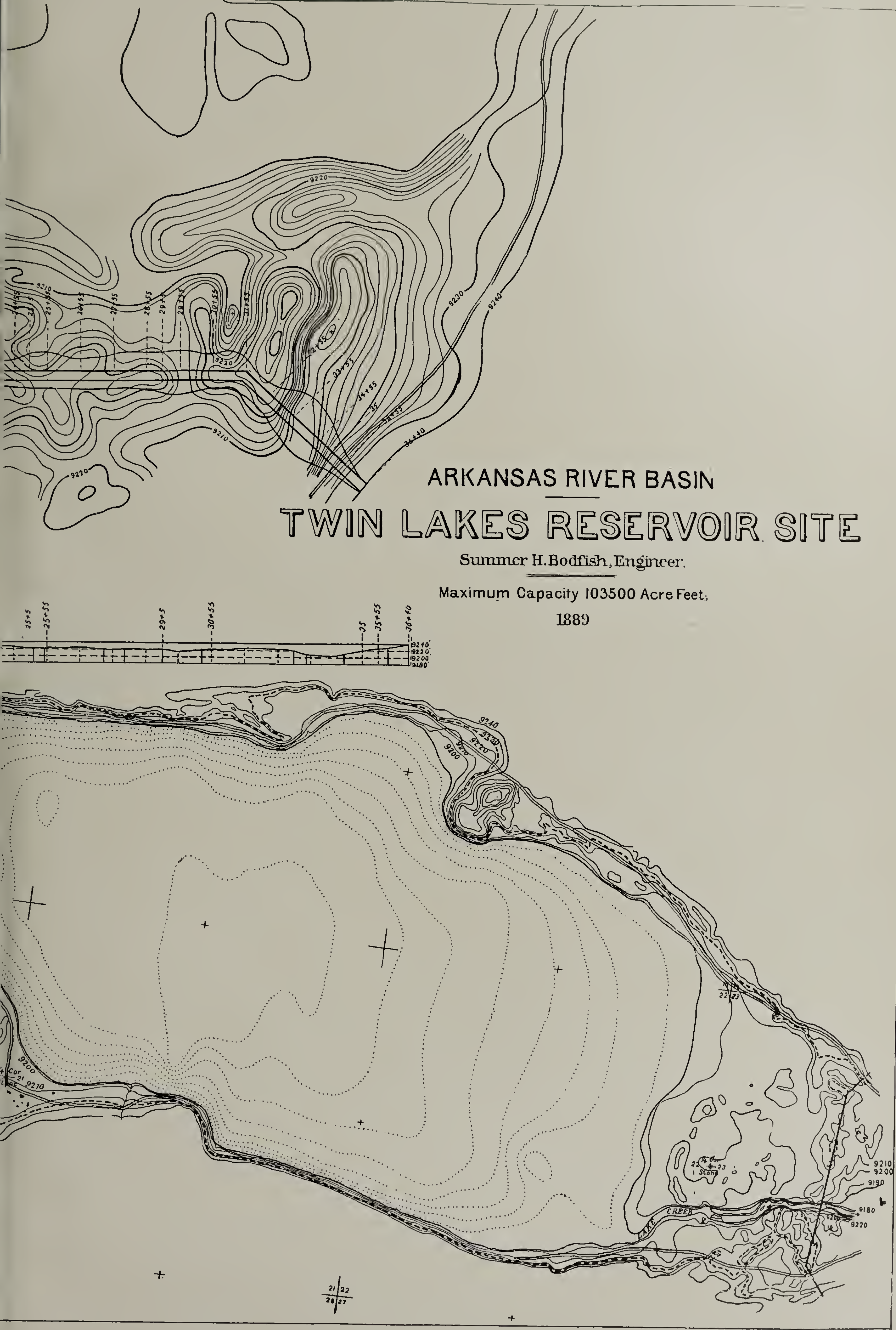
SCALE: 300 FT - 1 INCH.

Contour Interval 2 ft.



PLAN AND PROFI
OF
DAM SITE
Maximum Height 73 Fe
Length of Crest 3650 Fe





ARKANSAS RIVER BASIN

TWIN LAKES RESERVOIR SITE

Summer H. Bodfish, Engineer.

Maximum Capacity 103500 Acre Feet.

1889

SUN RIVER SYSTEM, MONTANA.

The region comprised in the Sun river system lies between the Teton river on the north, the Dearborn on the south, the Missouri on the east, and the crest of the main range of the Rocky mountains on the west, while the portion surveyed and studied during 1889 includes only the watershed of the Sun river, extending to the divides between the Teton on the north and the Dearborn river on the south.

The topography is simple. The Sun river, after rising in the Rockies, flows southward through them for about 60 miles, and then, turning abruptly, flows eastward through a canyon in the confining mountains and emerges on the level plain, through which it flows for 75 miles to its junction with the Missouri river at Great falls. Along its entire course through the plain the river has eroded a broad, level bottom. which averages about 1 mile in width and is from 5 to 25 feet above the surface of the water in the river. This bottom is bordered by a steeply sloping gravelly bluff, averaging from 300 to 500 feet in height, the top of which is the surface level of the plain, a generally flat and level bench land extending north and south to the next river channels, where the same bluff and bottom are repeated.

Though this region is far north, being between latitudes 47° and 48°, the low altitude compensates for the high latitude, the elevation at Great falls being but 3,300 feet above sea level and at Fort Shaw about 3,550 feet. There are no frosts here between April and October, and crops planted in the former month have ample time in which to mature.

The annual rainfall is very light, ranging during eighteen years from 4·2 to 14·8 inches at Fort Shaw as extremes, while scarcely more than 4·2 inches falls during the growing season from May 15 to August 15, thus making irrigation a necessity, while fortunately there is sufficient rainfall during the planting season in April and May to insure the germination of crops.

No good maps of the Sun river and its branches are in existence, in consequence of which it is very difficult to measure the areas of their catchment basins with any degree of accuracy. The following areas are from the best compilation that can be made:

The catchment basin of the South and Middle forks of the North fork above reservoir No. 4 is about 318 square miles, and of the North fork above reservoir No. 3 about 668 square miles, while the total catchment area above reservoir No. 1 and the head of canal No. 1 is about 1,172 square miles. The area above reservoir No. 2 and the head of canal No. 2 is 1,136 square miles. The catchment area of Willow creek above reservoir No. 6 is 37 square miles, and the total catchment of this creek above No. 5 is 87 square miles, exclusive of the catchment of No. 8 (Pl. CLVII).

Allowing an average annual rainfall of 19 inches on the mountain catchment of the river and a run-off over this area of 8 inches, which is not too large in view of the steep slopes and rocky character of the basin, the total precipitation available for irrigation will be about 425 acre-feet per square mile of catchment.

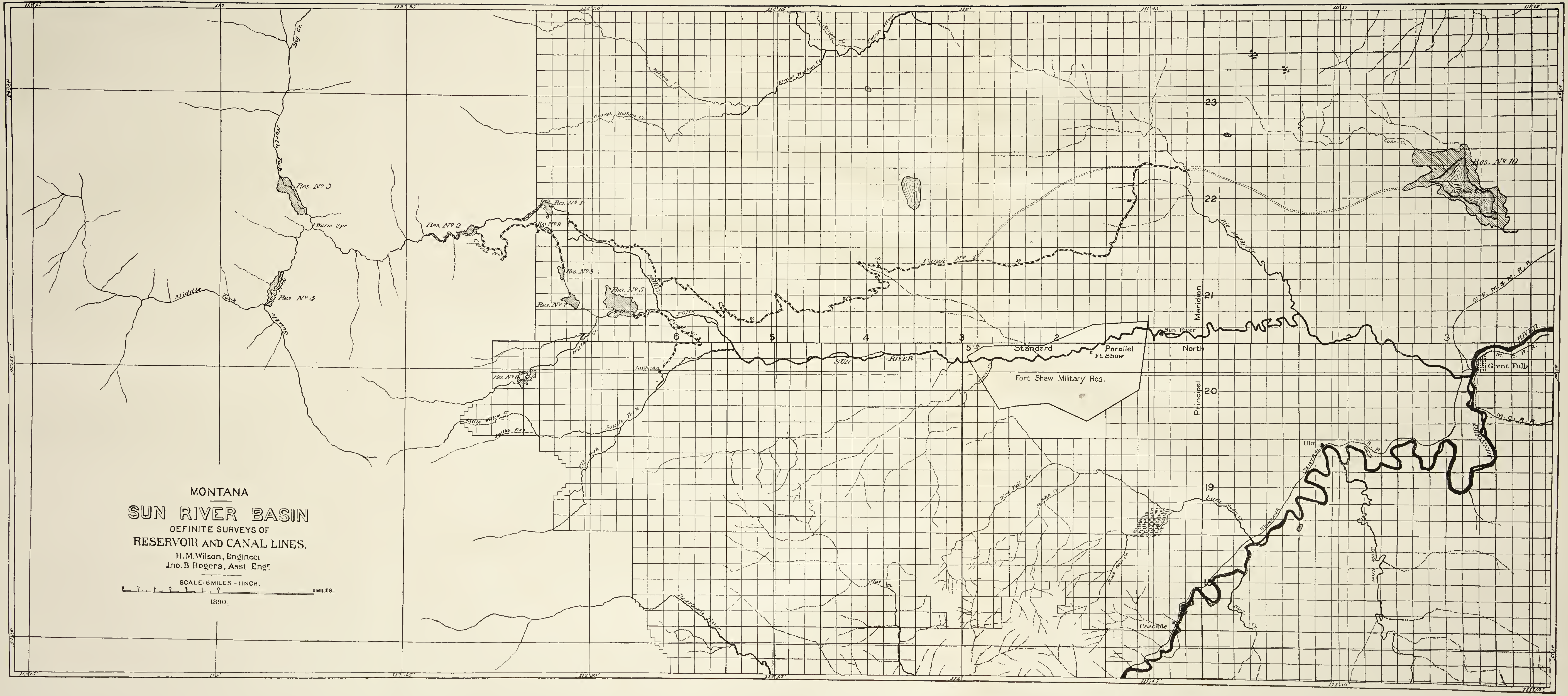
Allowing an average annual precipitation of 17 inches for the Willow creek catchment, as it is chiefly in foothill country, and an average run-off equal to 6 inches over the entire surface of the steep though not very rocky slopes, the available water will be about 320 acre-feet per square mile of catchment.

During 1889–'91 regular gaugings of the North fork of the Sun river have been made by the hydrographers of the Survey at a station located a short distance above the proposed head of canal No. 1, and of dam site No. 1. These give discharges which may be safely taken as a minimum, since the river is by all admitted to have been lower during the past season than for any previous one. These observations indicate a minimum annual discharge of 200 second-feet. From the best information now obtainable the average annual discharge in summer, at lowest stage of the river, is about 400 second-feet. In addition to this amount there are a few second-feet of water added by Willow creek and the South fork, both of which join the North fork below reservoir site No. 1.

From the data at hand the annual average discharge of the North fork available for storage above canal No. 1 is estimated to be 490,000 acre-feet, exclusive of the discharge available during the irrigating season, which is 50,000 acre-feet, which latter may be considered as all appropriated now. Of this amount 200,000 acre-feet will be available during six of the spring and summer months for diversion through canal No. 2 to the Willow creek for storage, or via canal No. 1 for storage in Benton lake site No. 10.

The total annual discharge of the North fork and of Willow creek is estimated to be 570,000 acre-feet, which includes the amount now appropriated by irrigators.

The crops are watered in June and the early part of July, and hay lands are flooded once or twice in August or early September after they have been cut. The early waterings are from one to three in number, according to the season, and last generally during ten hours for each piece of land. Though the duty now done does not probably exceed 80 acres per second-foot, it should easily reach 100 acres with a little economy and care. It may also at present be assumed to be 1¼ acre-feet per acre irrigated.



MONTANA

SUN RIVER BASIN

DEFINITE SURVEYS OF

RESERVOIR AND CANAL LINES.

H. M. Wilson, Engineer

Jno. B Rogers, Asst. Engr.

SCALE: 6 MILES - 1 INCH.

6 5 4 3 2 1 0 6 MILES

1890.

The total area of the big-bench land between the Sun and Teton rivers is about 530,000 acres, of which perhaps 395,000 acres could be profitably cultivated if a sufficient water supply can be provided. Between Willow creek and the South fork are 15,000 acres, of which at least 5,000 are good irrigable land. The bottom lands on the south side of the main lower Sun river east of Fort Shaw, and the bench lands south of the Sun river between it and the Missouri and east of Fort Shaw, contain in all about 60,000 acres of excellent irrigable land, which can readily be watered by a canal taken from the Sun river above Fort Shaw, utilizing any water that can be spared from the reservoirs above. Altogether there is a total of 460,000 acres reclaimable by the reservoirs, providing a sufficiently cheap supply of water can be obtained.

In order to bring this immense area to the highest state of cultivation, it is probable that a water supply for 300,000 acres will have to be provided, for, when fully cultivated and inhabited, at least 5 per cent of the area will be occupied by roads and buildings, 15 per cent by towns and pasture lands, which will receive water by percolation from the surrounding fields, and a large proportion more will be idle. Bottom lands, with a water right in perpetuity, range in value from $15 to $25 per acre exclusive of improvements, and it is probable that the bench lands will bring even better prices. At present fully 95 per cent of this land is owned by the government, and is worth only $1.25 per acre, though without water it is almost valueless except for grazing.

The surveys from which this report was prepared were made by Mr. John B. Rogers, under my direction as division engineer, in the summer of 1889. In surveying the reservoirs a bench mark was first established, which was located with reference to some natural object the elevation of which was assumed. From this bench as an initial point main transit and level lines were run through the different basins connecting them. From these main lines short lateral lines were run at frequent intervals to and connecting with a main line run approximately along the contour of the high-water surface of the proposed reservoir. From stations on these lines stadia distances were taken to such controlling points as proved necessary, and the topography was sketched on these lines in 4-foot contour intervals (Pl. CLVIII). The horizontal control was obtained by stadia measurements, and the vertical control by means of spirit level or the transit level and gradienter. The entire system controlling each reservoir was tied by completing the circuit and checking back on the initial point of the survey. At the dam site a special survey was made of a line through the axis of the proposed dam, on which contours were sketched at 2-foot intervals, the work here being performed entirely by transit, chain and spirit level.

The surveys of canal lines consisted merely of running out the grade contour, measuring the length of trestles, and ascertaining quantities of excavation at controlling points where cuts were necessary to save grade and distance. Notes were taken of the character of excavation and embankment so that a close preliminary estimate could be made of the cost of construction. The surveys of reservoirs and canal lines were connected with the Land Survey by tying to section and township corners. In a previous report was shown a general map of the Sun river project, with detailed maps showing the location, by land lines, of the various reservoirs surveyed.[1]

RESERVOIRS.

In the following estimates, in the case of the gravity section —, masonry dams —, the material of which they are intended to be constructed is assumed to be the best uncoursed rubble masonry or concrete, and the quantities are calculated on cross sections obtained by the method outlined by Mr. Edward Wegmann, jr., in his work on the "Design and Construction of Masonry dams."

The rock-filled dams are of the California nydraulic mining type with wooden face, the rear slope is 1 on 1, sometimes 4 on 3, and the water slope 2 or 2½ on 1.

All of the earth dams are intended to be constructed of a good puddle mixture of clayey earth and gravel or coarse sand, well bedded in layers and tramped over and packed as they are built up. The quantities of excavation in the canals are estimated separately for earth, loose rock, and solid or blast rock.

The reservoir capacities given are the volumes of water available for diversion to the canals after deducting the loss by evaporation, which for the storage period occurring in the first half of the year is found to be equivalent to a loss of about 18 inches over the surface exposed.

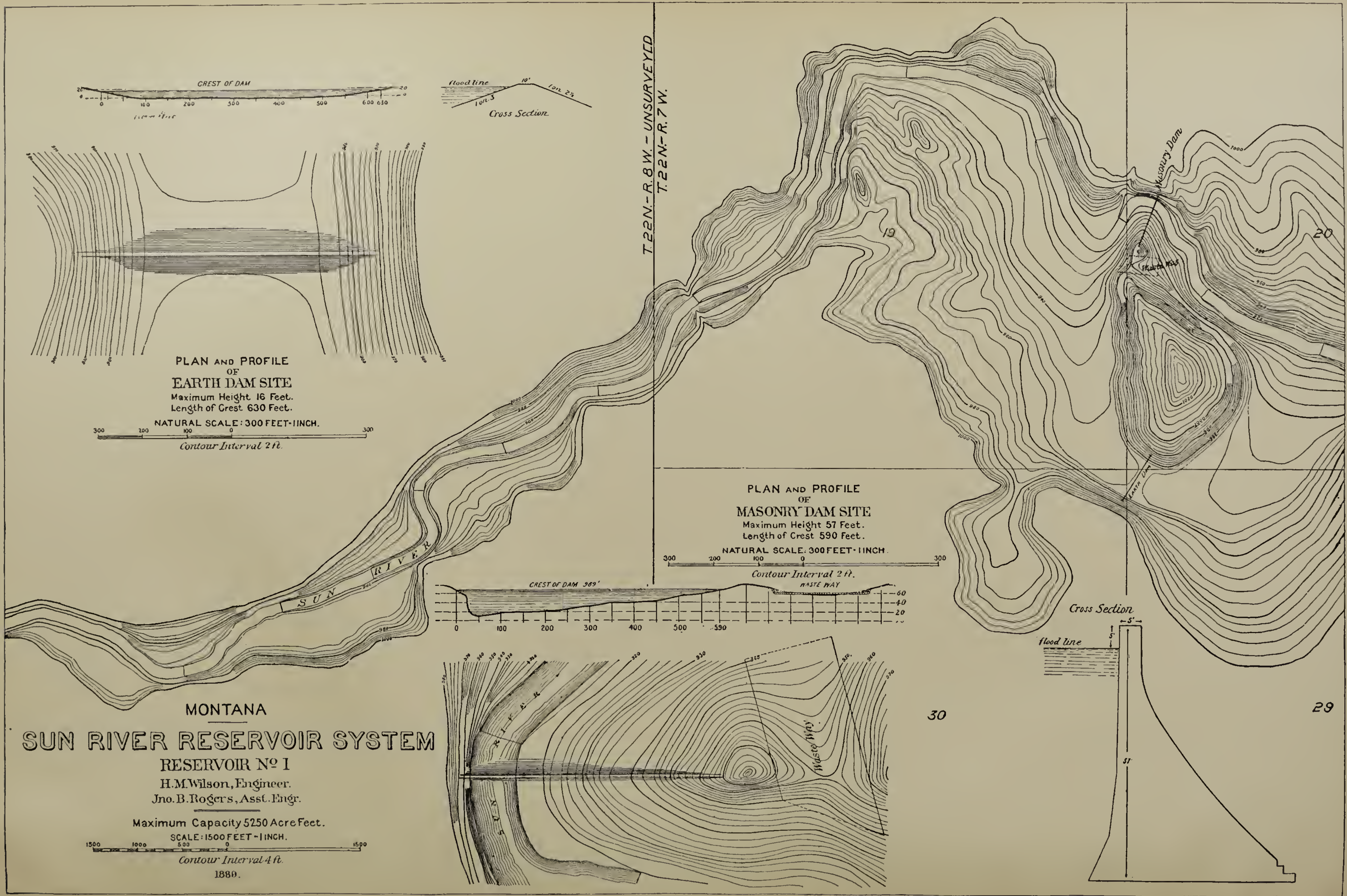
Reservoir No. 1 will be closed by a dam the height of which is limited by the position of a natural wasteway and the general topography of its site. Its total height will be 57 feet above its foundation. This reservoir will require two dams, a masonry or rock-filled dam on the Sun river, and an earth bank to close a side outlet channel the bottom of which is 15 feet below its crest. (Pl. CLIX.)

The foundation and abutments are of solid sandstone formation, rising nearly perpendicular on the left bank of the river, while on the right bank the rise is about 1 in 10. The river at this point is 105 feet wide and 7 feet in maximum depth, with an average fall of 15 feet per mile through the reservoir site. The main dam will be 57 feet in maximum height, 590 feet long, and 5·3 feet wide on top, with its flood line 5 feet below the crest. The maximum available depth of water above the sill of the discharge sluice will be 55 feet.

The secondary earth dam will be located directly south of the main dam and one-half mile distant from it and will be 630 feet long, 10 feet wide on top, and 15 feet in maximum height. The slope of the inner face of this dam will be 3 to 1; of the outer face, 2½ to 1, and the inner face will have 6 inches of paving to protect it against wave action.

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. II, 1889-'90, pp. 120-128.



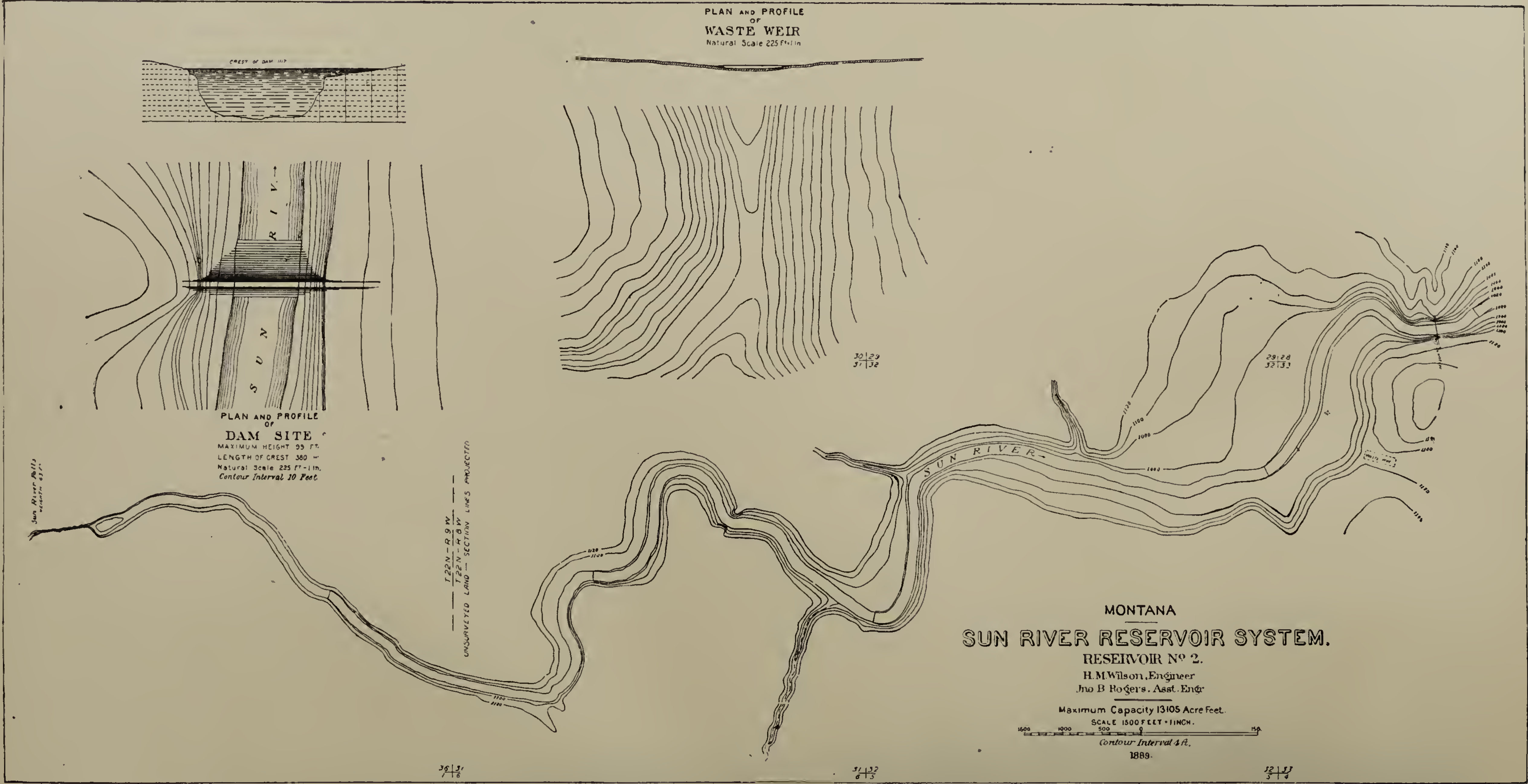
MONTANA

SUN RIVER RESERVOIR SYSTEM
RESERVOIR Nº I
H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

Maximum Capacity 5250 Acre Feet.
SCALE: 1500 FEET - 1 INCH.
Contour Interval 4 ft.
1889.

PLAN AND PROFILE
OF
EARTH DAM SITE
Maximum Height 16 Feet.
Length of Crest 630 Feet.
NATURAL SCALE: 300 FEET - 1 INCH.
Contour Interval 2 ft.

PLAN AND PROFILE
OF
MASONRY DAM SITE
Maximum Height 57 Feet.
Length of Crest 590 Feet.
NATURAL SCALE: 300 FEET - 1 INCH.
Contour Interval 2 ft.



MONTANA

SUN RIVER RESERVOIR SYSTEM.

RESERVOIR Nº 2.

H. M. Wilson, Engineer
Jno B Rogers. Asst. Engr

Maximum Capacity 13105 Acre Feet.
SCALE 1500 FEET = 1 INCH.
1500 1000 500 0 1500
Contour Interval 4 ft.
1889.

There is a natural wasteway 120 feet south of the south end of the main dam, from which it is separated by a low hill. This wasteway will discharge into the river below the dam by a separate side channel. It is in sandstone rock, 150 feet wide at the flood line and 4 feet in greatest depth below that line. A maximum flood discharge of 5,000 second-feet has been estimated for at this point, which volume will necessitate deepening and widening the wasteway sufficiently to give a cross section of 600 square feet and a slope of 1 foot in 100. It will be 200 feet wide, 3½ feet deep, and 390 feet long.

Surface areas and capacities of reservoir No. 1 for different heights.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
948	41	150	1, 862
952	45	185	2, 534
956	49	207	3, 318
960	53	241	4, 215
964	57	275	5, 249

The following table gives a preliminary estimate of the cost of constructing dams to Reservoir No. 1:

[Reservoir capacity, 4,894 acre-feet.]

	Masonry dam.	Rock-filled dam.
Masonry in dam, 4,280 cubic yards, at $9	$38, 520·00	
Masonry in wasteway, 200 cubic yards, at $9	1, 800·00	$1, 800·00
Earth in secondary dam, 15,670 cubic yards, at 12 cents	1, 880·00	1, 880·00
Loose rock in dam, 27,560 cubic yards, at $2		55, 120·00
Excavation for foundation, masonry dam, 1,500 cubic yards, at 40 cents	600·00	
Excavation for foundation, rock dam, 2,820 cubic yards, at 40 cents		1, 128·00
Excavation for foundation, earth dam, 3,760 cubic yards at 40 cents	1, 504·00	
Excavation for foundation, wasteway, 5,780 cubic yards, at 40 cents	2, 312·00	2, 312·00
Lumber, 89 M. B. M., at $25		2, 224·00
6-inch paving, earth dam, 2,980 square yards, at 90 cents	2, 682·00	2, 682·00
12-inch paving, waste-way, 8,840 square yards, $1·25	11, 050·00	11, 050·00
8-inch paving, wasteway, 2,300 square yards, at $1	2, 300·00	2, 300·00
Gate tower and outlet sluices		25, 000·00
Total cost	62, 648·00	107, 000·00
Plus 10 per cent for contingencies	68, 902·00	117, 700·00
Cost per acre-foot stored	14·09	24·45

Not only is the first cost of the rock-filled dam greater, but it costs more to maintain, and the loss of water through it by percolation is a large item.

The dam for Reservoir No. 2, which is situated on the Sun river about 3 miles above reservoir No. 1, is to be constructed of masonry, and will be 150 feet long at the bottom. The canyon walls here rise abruptly to within 15 feet of the dam crest were the canyon is only 245 feet in width (Pl. CLX). The greatest height of the dam above its base has been fixed as 99 feet, the crest being 9 feet above the flood line, 389 feet long, with a top width of 9·2 feet. This reservoir is provided with a natural wasteway situated 1,800 feet south of the dam site, 50 feet wide at flood line, and 2 feet deep, with slopes rising with an inclination of 1 in 10 for a vertical distance of 20 feet on either side. The wasteway discharges around a small hill into a drainage line which will lead its waters back into the Sun river some distance below the dam, and is intended also to serve as the head of canal No. 2, which will receive its water supply through this escape. The wasteway will be 110 feet wide, 6 feet deep, and 400 feet long, excavated wholly in earth, which will be paved to protect it against erosion.

Capacity of Reservoir No. 2.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1, 084	73	244	5, 790
1, 088	77	264	6, 805
1, 092	81	284	7, 900
1, 096	85	303	9, 073
1, 100	89	327	10, 332
1, 104	93	346	11, 678
1, 108	97	367	13, 013

The following table gives a preliminary estimate of the quantities of material required and the cost of constructing this dam:

Reservoir capacity .... acre-feet..	13, 013
Masonry in dam, 11,832 cubic yards, at $9	$106, 488·00
Masonry in wasteway, 355 cubic yards, at $9	3, 195·00
Excavation for foundation, 820 cubic yards, at 40 cents	328·00
Excavation for wasteway, 5,065 cubic yards, at 10 cents	506·00
Rock ballast in wasteway, 1,126 cubic yards, at $1	1, 126·00
12-inch paving in wasteway, 4,888 square yards, at $1·25	6, 110·00
8-inch paving in wasteway, 1,300 square yards, at $1	1, 300·00
Total cost	119, 053·00
Plus 10 per cent for contingencies	130, 958·00
Cost per acre-foot stored	10·06

Reservoir No. 3 is located on the North Fork of the Sun river, at an elevation of 510 feet above Reservoir No. 2 (Pl. CLXI). The foundations and abutments of the dam are of granite. At this point the river is 95 feet in width and 4 feet in greatest depth, and has an average fall of 26 feet per mile through the reservoir site. This reservoir will be closed by a dam which may be economically constructed to a total height of 122 feet above the foundation, its crest being 10 feet above flood line. Its length at bottom will be 95 feet, on top it will be 470 feet long and 11·3 feet wide, and the available depth of water above the sill of the discharge sluice will be 118 feet.

A wasteway having a capacity of 3,500 second-feet will in all probability carry off the greatest flood discharge of the North Fork at this point. This will have to be constructed at one end of the dam by blasting in solid rock, though a large portion of the flood could be discharged through the undersluices. The cross section of the wasteway will be 40 by 10 feet with a slope of about 1 foot in 100.

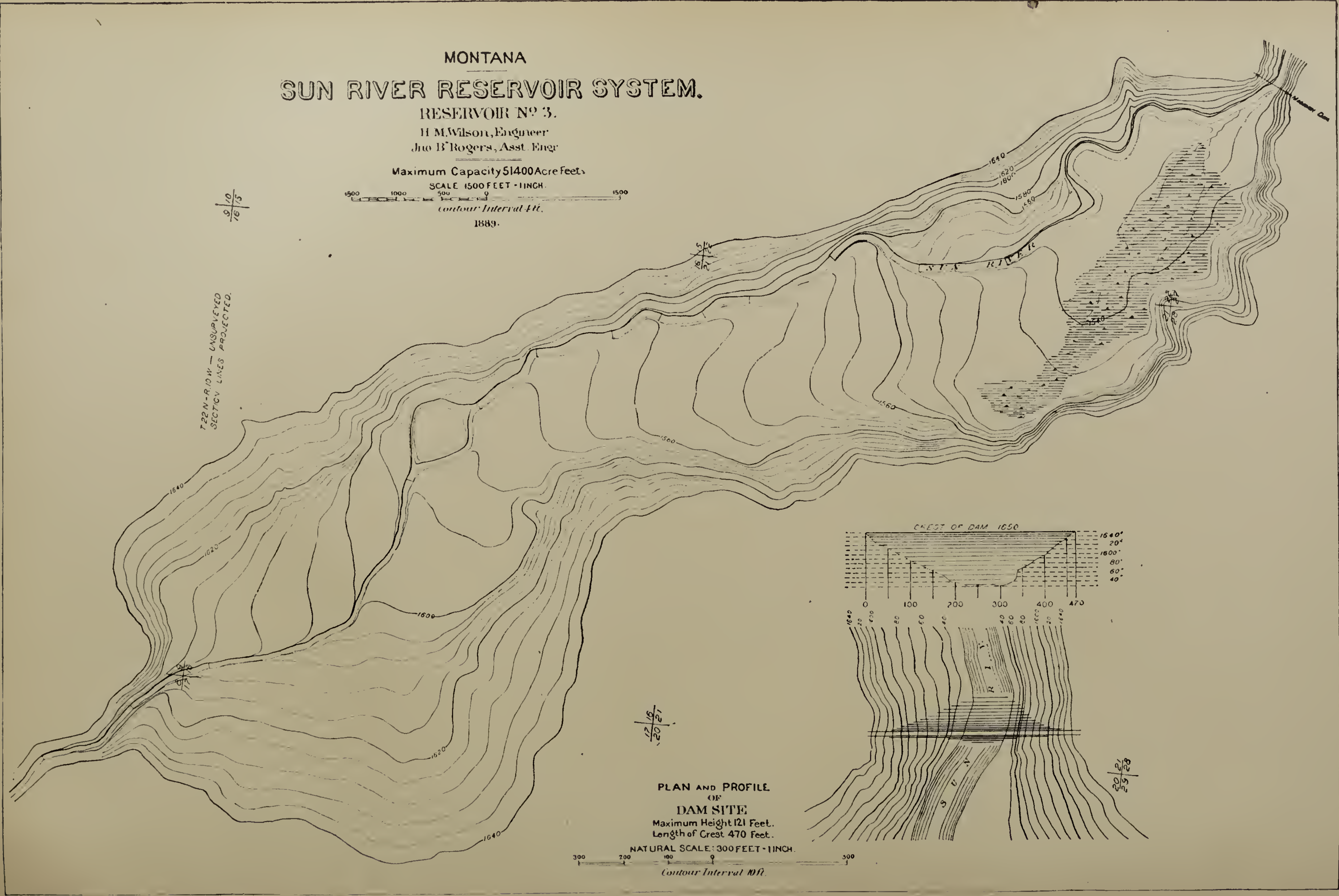
MONTANA

SUN RIVER RESERVOIR SYSTEM.

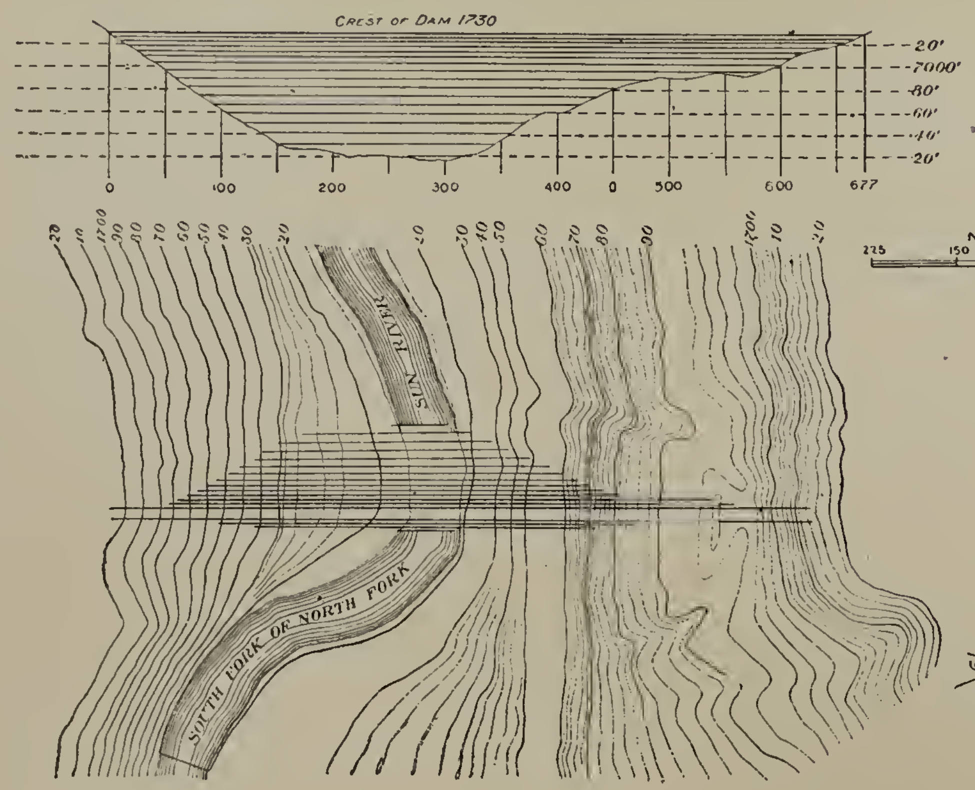
RESERVOIR Nº 3.

H. M. Wilson, Engineer
Jno B. Rogers, Asst. Engr

Maximum Capacity 51400 Acre Feet.
SCALE 1500 FEET - 1 INCH.
Contour Interval 4 ft.
1889.



PLAN AND PROFILE
OF
DAM SITE
Maximum Height 121 Feet.
Length of Crest 470 Feet.
NATURAL SCALE: 300 FEET - 1 INCH.
Contour Interval 10 ft.



PLAN AND PROFILE
OF
DAM SITE.
Maximum Height 113 Feet.
Length of Crest 677 Feet.
NATURAL SCALE: 225 FEET = 1 INCH.
225 150 75 0 225
Contour Interval 2 ft.

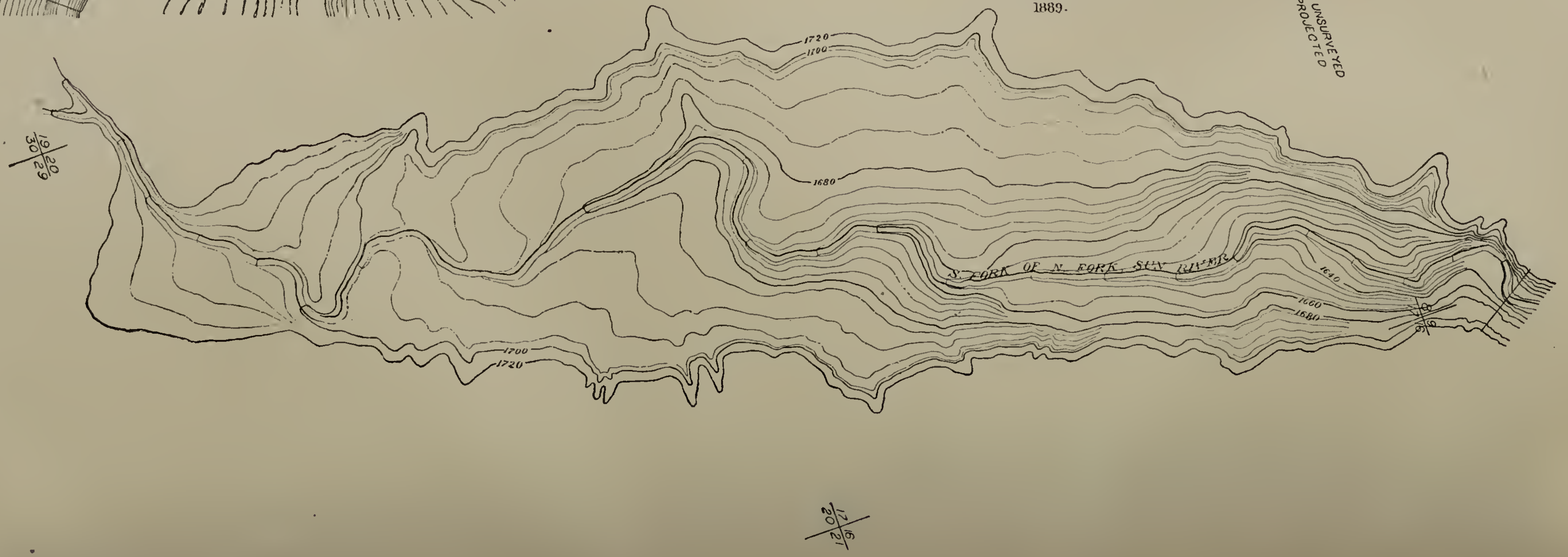
MONTANA

SUN RIVER RESERVOIR SYSTEM.

RESERVOIR Nº 4.

H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

Maximum Capacity 20315 Acre Feet.
SCALE: 1500 FEET = 1 INCH.
1500 1000 500 0 1500
Contour Interval 4 ft.
1889.



Capacity of Reservoir No. 3.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1620	98	788	32, 648
1624	102	839	35, 901
1628	106	902	39, 382
1632	110	972	43, 130
1636	114	1, 039	47, 152
1640	118	1, 102	51, 433

The following table gives a preliminary estimate of the quantities of material and cost of constructing this dam:

Reservoir capacity acre-feet	50, 056
Masonry in dam, 25,464 cubic yards, at $9	$229, 175·00
Excavation for foundation, 1,850 cubic yards, at 50 cents	925·00
Total cost	230, 100·00
Plus 10 per cent for contingencies	253, 110·00
Cost per acre-foot, stored	5·00

In the above no estimate is made for cost of wasteway, as the material excavated for that purpose will be used in the construction of the dam.

Reservoir No. 4 is located on the South Fork, 4½ miles above the forks, and is 600 feet higher than Reservoir No. 2 (Pl. CLXII). The foundation and abutments are of granite. The river at this point is 45 feet wide and 3 feet in maximum depth and has an average fall of 31 feet per mile through the reservoir site. This reservoir will be closed by a dam which will be 175 feet long on the bottom; its crest will be 677 feet long, 10.6 feet wide, and 113 feet high above its foundation. The height of the crest above flood line will be 10 feet, and the available maximum depth of water will be about 110 feet.

A wasteway having a capacity of 1,700 second-feet will in all probability discharge the greatest flood volumes carried by the South fork of the North fork at this point. This wasteway, like that of Reservoir No. 3, will have to be blasted out of the solid rock at the end of the dam, and will require a cross section 25 by 9 feet with a fall of 1 foot in 100.

Capacity of Reservoir No. 4.

Contour.	Available depth.	Surface area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1, 692	85	376	6, 654
1, 696	89	429	8, 262
1, 700	93	459	10, 037
1, 704	97	477	11, 910
1, 708	101	499	13, 862
1, 712	105	523	15, 905
1, 716	109	550	18. 051
1, 720	113	581	20, 315

The quantities of material and the cost for building masonry and rock-filled dams are roughly estimated to be as follows:

[Reservoir capacity, 19,591 acre-feet.]

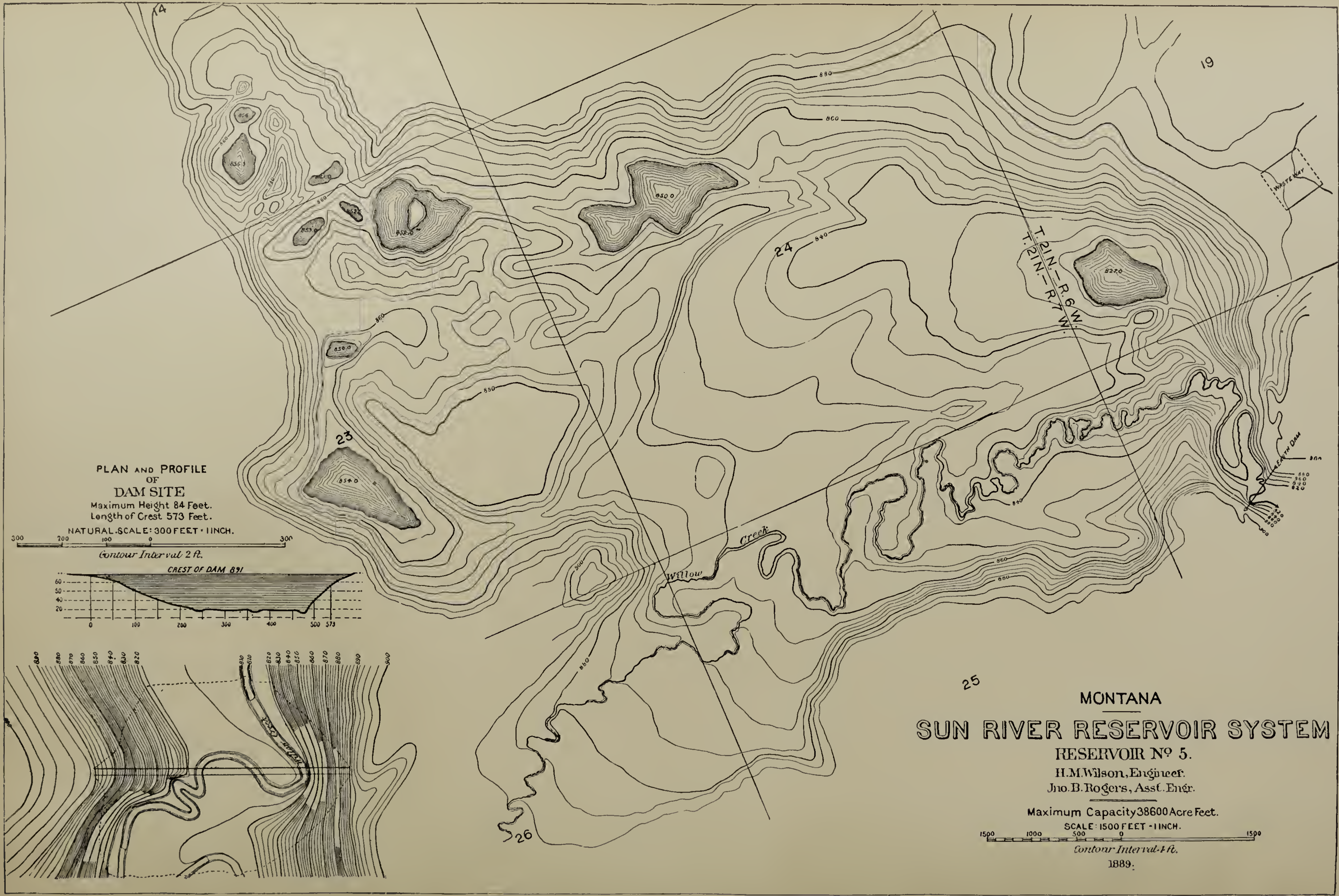
	Masonry.	Rock filled.
Masonry, 27,700 cubic yards, at $9	$249, 300·00	....
Loose rock, 118,300 cubic yards, at $2	....	$236, 600·00
Excavation for foundation, 2,300 cubic yards, at 50 cents	1, 150·00	....
Excavation for foundation, 4,900 cubic yards, at 50 cents	....	2, 450·00
Lumber, 154 M., B. M., at $20	....	3, 080·00
Gate tower and outlet sluice	....	30, 000·00
Total cost	250, 450·00	272, 130·00
Plus 10 per cent for contingencies	275, 495·00	299, 343·00
Cost per acre-foot	14·05	15·27

The excavation for the wasteway will not add to the cost of the work, as the material removed can be used in the construction of the dam. The rock-filled dam is not only more costly than the masonry structure, but it is less safe, and the loss of water by percolation through it is considerable.

Reservoir No. 5 is located on Willow creek, about 2 miles above its junction with the Sun river, where the foundation and abutments are of earth (Pl. CLXIII). Willow creek is but a small stream discharging a few second-feet, and is entirely inadequate to supply this reservoir. A canal line was therefore run from the top of Reservoir No. 2 which will supply this reservoir and three smaller ones lying above it from the flood waters of Sun river. The dam for this reservoir will be constructed of earth, its location and height having been fixed by the position of several natural outlets or wasteways. It will be 250 feet long on the bottom, 573 feet long on top, and 84 feet in greatest height, while the flood line will be 7 feet below the crest.

A good wasteway can be constructed involving a small amount of earth excavation at a point 3,000 feet northeast of the dam site. This wasteway will have sufficient capacity to carry off a large amount of water in a short space of time in case one or more of the reservoirs above it, Nos. 6, 7, or 8, should rupture, or it should be necessary to empty them rapidly. Owing to the fact that two of these reservoirs are to be filled by means of Canal No. 2, on the line of which is an ample escape, it will in all probability never be necessary to waste any water over their weirs, as the supply admitted can be readily controlled; still, as they are to be closed by earth dams it has been deemed advisable to provide ample wasteway. The wasteway of Reservoir No. 5 has been calculated so as to discharge 10,000 second-feet and will require a cross-section 500 feet wide by 7 deep and will be 500 feet long.

The dam will be 15 feet wide on top, the inner slope will be 1 on 3 and the outer slope 1 on 2½, and the water slope will be paved with dry stone pitching from the crest to within 40 feet of the bottom, below which the paving will be 6 inches in depth to within 5 feet of the bottom.



MONTANA

SUN RIVER RESERVOIR SYSTEM

RESERVOIR Nº 5.

H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

Maximum Capacity 38600 Acre Feet.
SCALE: 1500 FEET - 1 INCH.

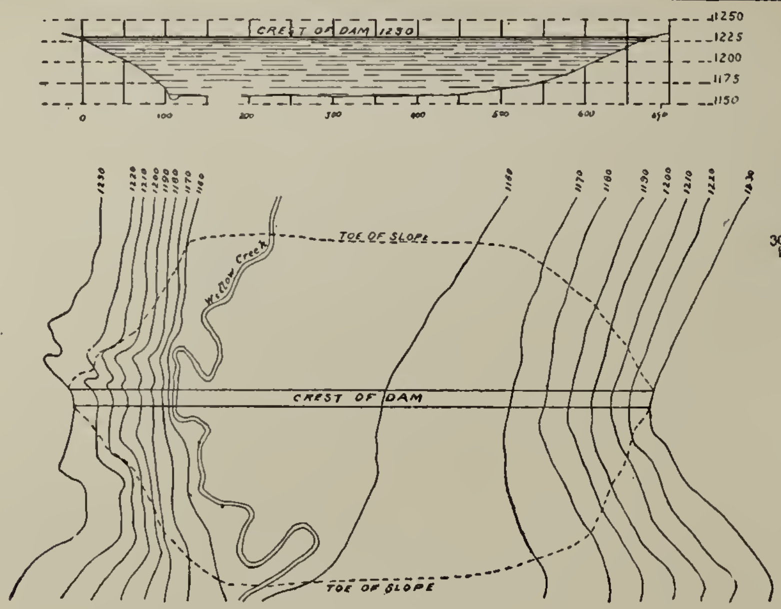
Contour Interval 4 ft.

1889.

PLAN AND PROFILE OF DAM SITE

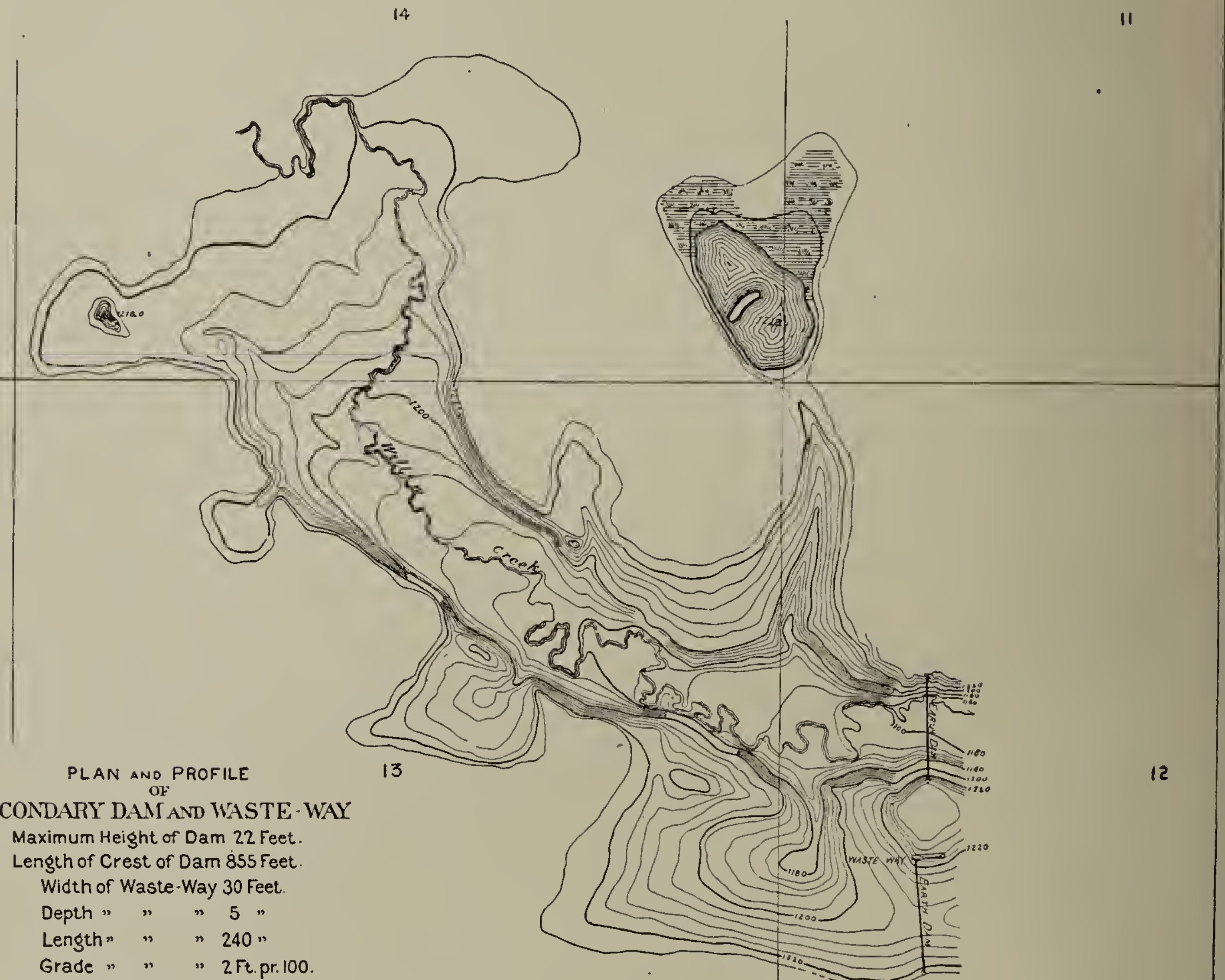
Maximum Height 84 Feet.
Length of Crest 573 Feet.
NATURAL SCALE: 300 FEET - 1 INCH.

Contour Interval 2 ft.



PLAN AND PROFILE OF DAM SITE

Maximum Height 74 Feet.
Length of Crest 690 Feet.
NATURAL SCALE: 300 FEET - 1 INCH
300 200 100 0 300
Contour Interval 10 ft.

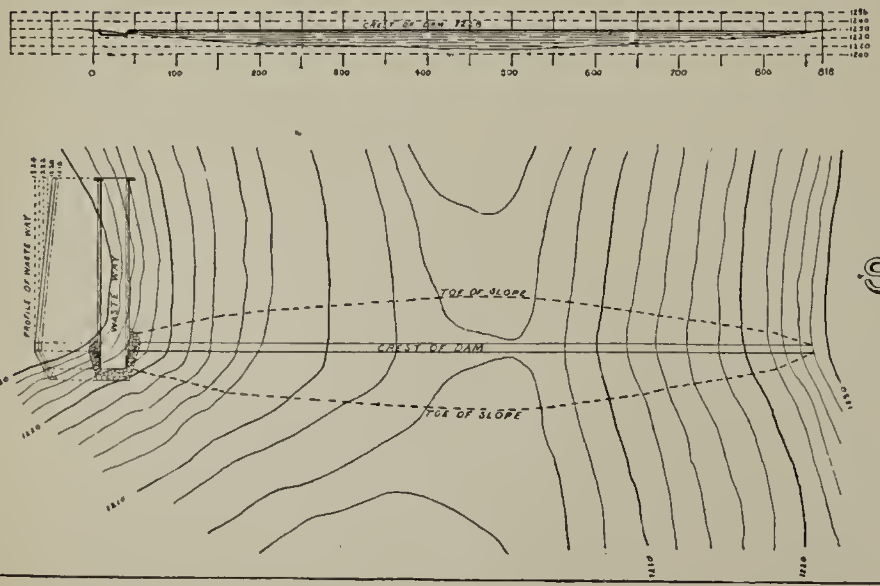


PLAN AND PROFILE OF SECONDARY DAM AND WASTE-WAY

Maximum Height of Dam 22 Feet.
Length of Crest of Dam 855 Feet.
Width of Waste-Way 30 Feet.
Depth " " " 5 "
Length " " " 240 "
Grade " " " 2 Ft. pr. 100.

NATURAL SCALE: 300 FEET - 1 INCH
300 200 100 0 300
Contour Interval 4 ft.

T. 20 N. - R. 8 W.
T. 20 N. - R. 7 W.



MONTANA

SUN RIVER RESERVOIR SYSTEM

RESERVOIR No. 6.

H. M. Wilson, Engineer
Jno. B. Rogers, Asst. Engr.

Maximum Capacity 6550 Acre Feet.
SCALE: 1500 FEET - 1 INCH
1500 1000 500 0 1500
Contour Interval 4 ft.
1889.

Capacity of Reservoir No. 5.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
860	60	764	10, 215
864	64	909	13, 559
868	68	1, 061	17, 497
872	72	1, 195	22, 009
876	76	1, 318	27, 036
880	80	1, 433	32, 537
884	84	1, 606	38, 612

Quantities of materials required in the construction of the dam and wasteway and the preliminary estimate of cost.

[Reservoir capacity, 36,605 acre-feet.]

	Dam.	Wasteway.
Earth in dam, 231,927 cubic yards, at 30 cents	$69, 578	
Earth excavation, 3,520 cubic yards, at 10 cents		$352
Masonry 520 cubic yards, at $8		4, 160
Rock ballast, 6,170 cubic yards, at $1		6, 170
8-inch paving, 28,700 square yards, at $1		28, 700
6-inch paving, 6,016 square yards, at 90 cents	5, 415	
12-inch paving, 5,780 square yards, at $1·25	7, 225	
Gate tower and outlet sluice	30, 000	
	112, 218	39, 382
Total cost	151, 600·00	
Plus 10 per cent for contingencies	166, 760·00	
Cost per acre-foot stored	4·55	

No estimate is made for the cost of excavating the foundation, as the material so removed will be used in the dam.

Reservoir No. 6 is located on Willow creek, about 6 miles above Reservoir No. 5, and is 340 feet higher (Pl. CLXIV). Foundation and abutments are of earth. The dam will be 400 feet long on the bottom and its crest will be 6 feet above the flood line. The length on top will be 690 feet, the top width 20 feet, and the maximum height 74 feet. The back or inner slope will be 1 on 3 and the outer slope 1 on 2½, and the inner slope will be paved to protect it against wave action with a uniform depth of 6 inches of dry stone paving from the crest to within 5 feet of the bottom.

It will also be necessary to construct a smaller dam 600 feet east of the main one, which, in the deepest place, is 18 feet below the flood line. This secondary dam will be a simple earth bank 855 feet long, 10 feet wide on top, and averaging about 15 feet in height. A small wasteway will have to be constructed at one end of it and the water discharged through it will flow back into Willow creek by a short branch drainage line. As designed, this wasteway will be 30 feet wide and 5 feet deep, and will be 240 feet long, with a grade of 2 feet in 100. The walls of this wasteway will be of masonry, and the bed will be ballasted 8 inches in depth, over which will be 12 inches of paving.

Capacity of Reservoir No 6.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1,200	50	104	1,649
1,204	54	129	2,113
1,208	58	155	2,681
1,212	62	184	3,359
1,216	66	221	4,168
1,220	70	298	5,247
1,224	74	378	6,554

Quantities and cost of constructing Reservoir No. 6.

[Reservoir capacity, 6,081 acre-feet.]

	Main dam.	Small dam.
Earth embankment, 264,630 cubic yards, at 25 cents	$66,157	
Earth embankment, 26,935 cubic yards, at 20 cents		$5,387
Masonry in wasteway, 125 cubic yards, at $8		1,000
Rock ballast in wasteway, 200 cubic yards, at $1		200
12-inch paving in wasteway, 860 square yards, at $1·25		1,075
10 inch paving in wasteway, 300 square yards, at $1·10		330
6-inch paving in wasteway, 13,330 square yards, at $1	13,330	
6-inch paving in wasteway, 4,680 square yards, at $1		4,680
Gate tower and sluice	20,000	
	99,487	12,672
Total cost	112,159·00	
Plus 10 per cent for contingencies	123,375·00	
Cost per acre-foot stored	20·29	

Reservoir No. 7 will be formed by damming a narrow valley just below two small alkali lakes (Pl. CLXV). It is located upon a natural water course about 1½ miles from Willow Creek and 2 miles west of Reservoir No. 5, which lies 100 feet below it. It will be supplied by the canal taken from the top of Reservoir No. 2, and will drain into No. 5. The dam will be 3,160 feet in length and 15 feet in width on top. The upper slope will be 1 on 3 and the lower face will have a slope of 1 on 2½. The dam will be constructed of earth, its maximum height being 41 feet and its crest 5 feet above the flood height. The inner or back slope will be paved with 6 inches of hand-packed rock to protect it against wave action.

It will be necessary to construct a wasteway at the south end of the dam sufficiently large to carry off the full capacity of canal No. 2, plus the local drainage caught above the dam. A channel 85 feet wide and 5 feet deep will be sufficiently large for the purpose.

Capacity of Reservoir No. 7.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
940	22	220	2,514
944	26	241	3,441
948	30	270	4,466
952	34	293	5,592

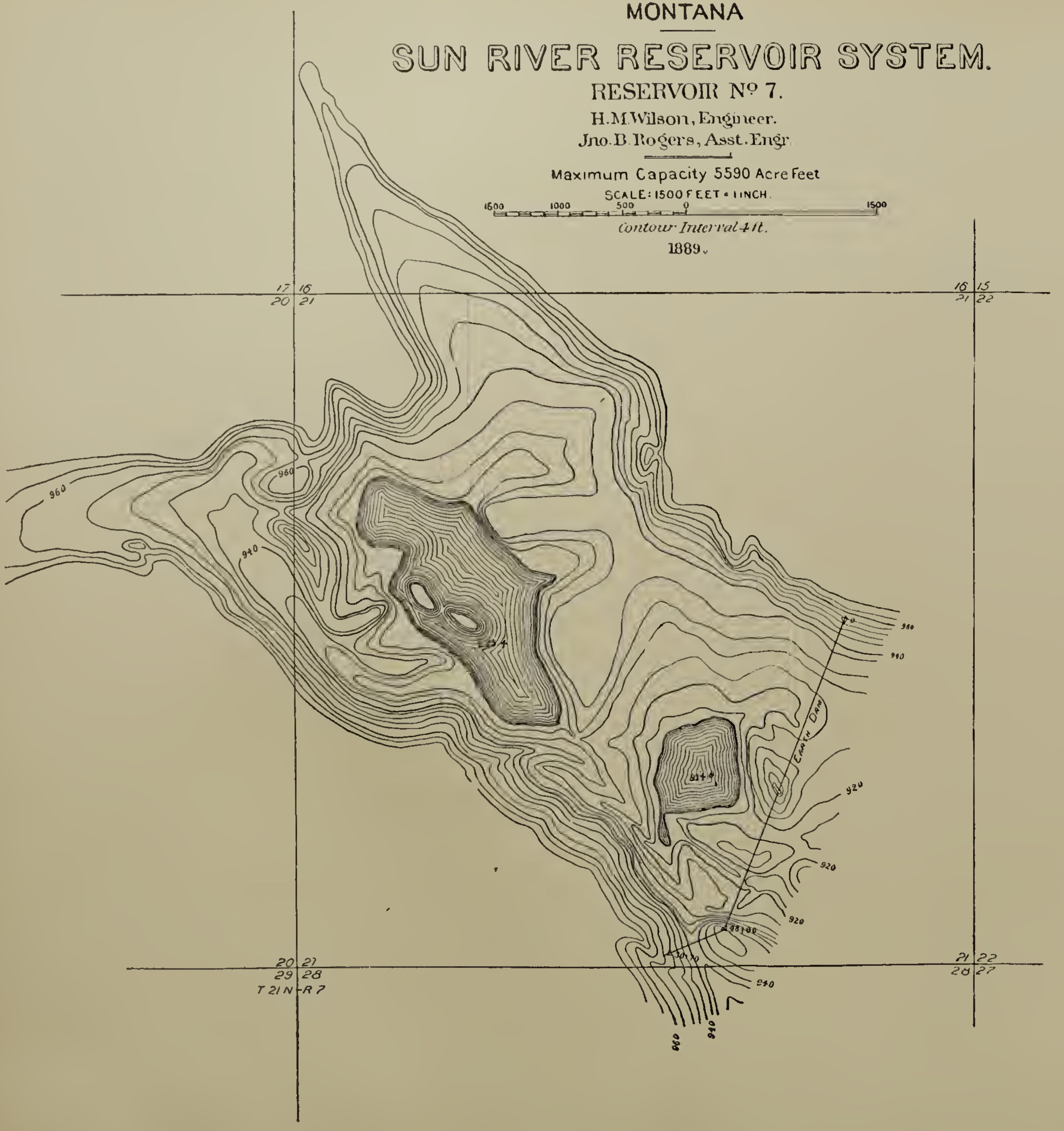
MONTANA

SUN RIVER RESERVOIR SYSTEM.

RESERVOIR Nº 7.

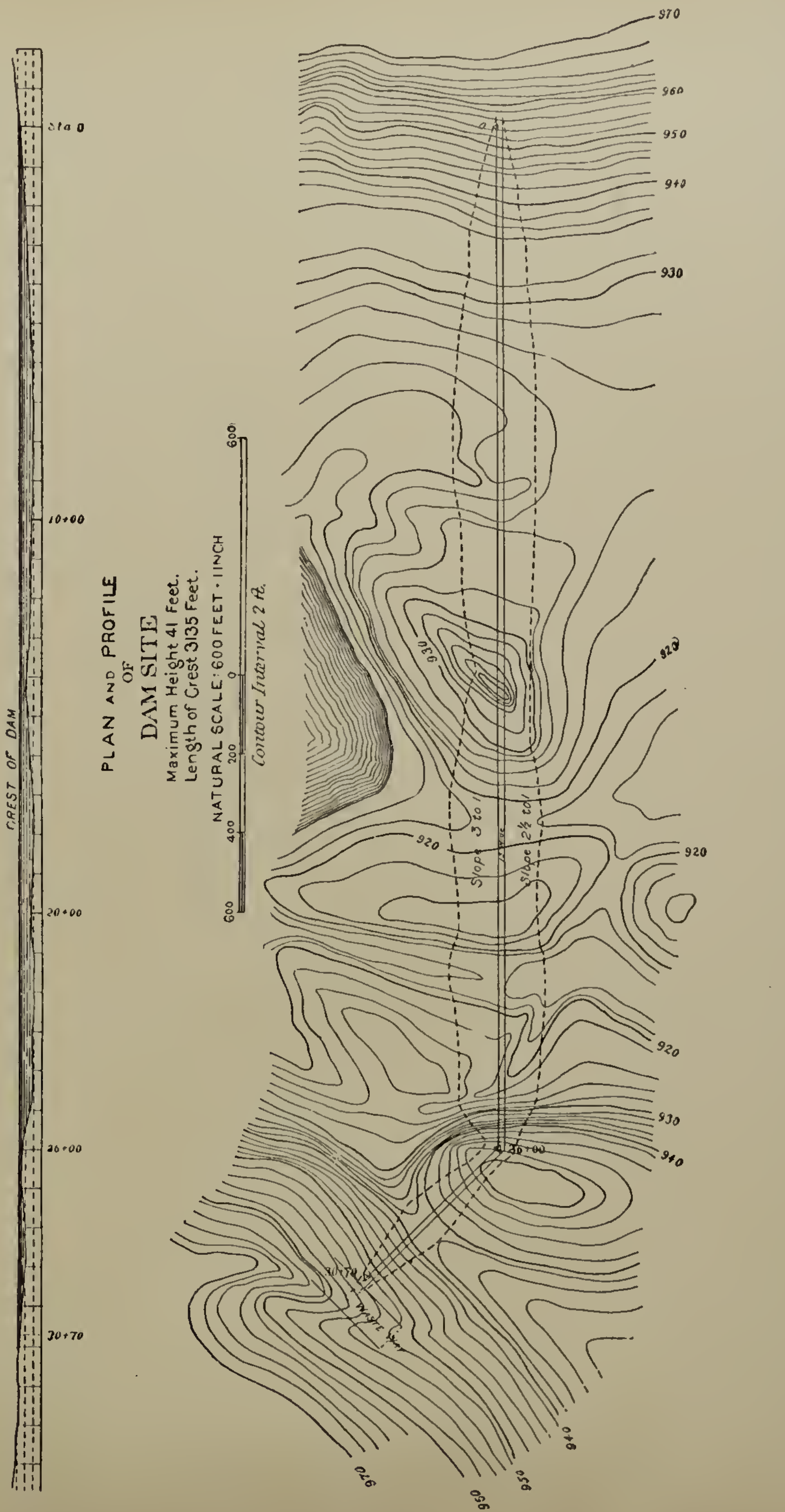
H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

Maximum Capacity 5590 Acre Feet
SCALE: 1500 FEET = 1 INCH.
Contour Interval 4 ft.
1889.



PLAN AND PROFILE OF DAM SITE

Maximum Height 41 Feet.
Length of Crest 3135 Feet.
NATURAL SCALE: 600 FEET = 1 INCH
Contour Interval 2 ft.



MONTANA

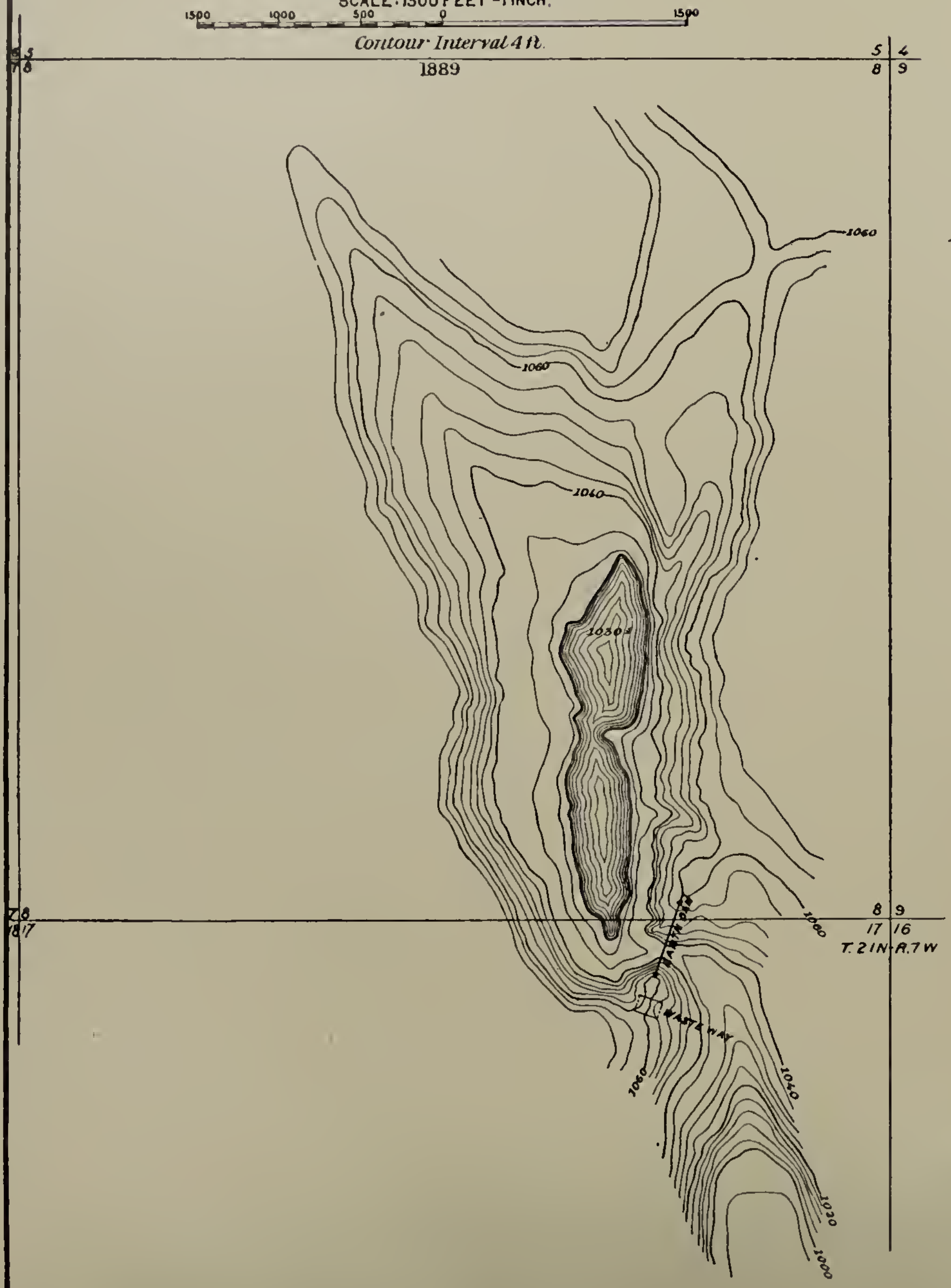
SUN RIVER RESERVOIR SYSTEM

RESERVOIR Nº 8.

H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

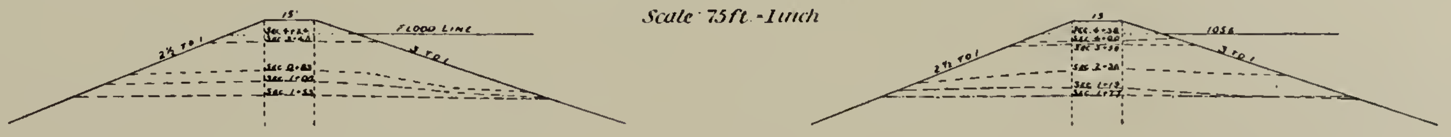
Maximum Capacity 1735 Acre Feet.
SCALE: 1500 FEET - 1 INCH.

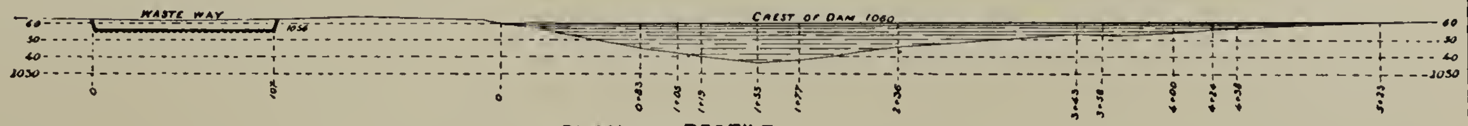
Contour Interval 4 ft.
1889



SECTIONS OF EARTH DAM

Scale 75 ft. - 1 inch

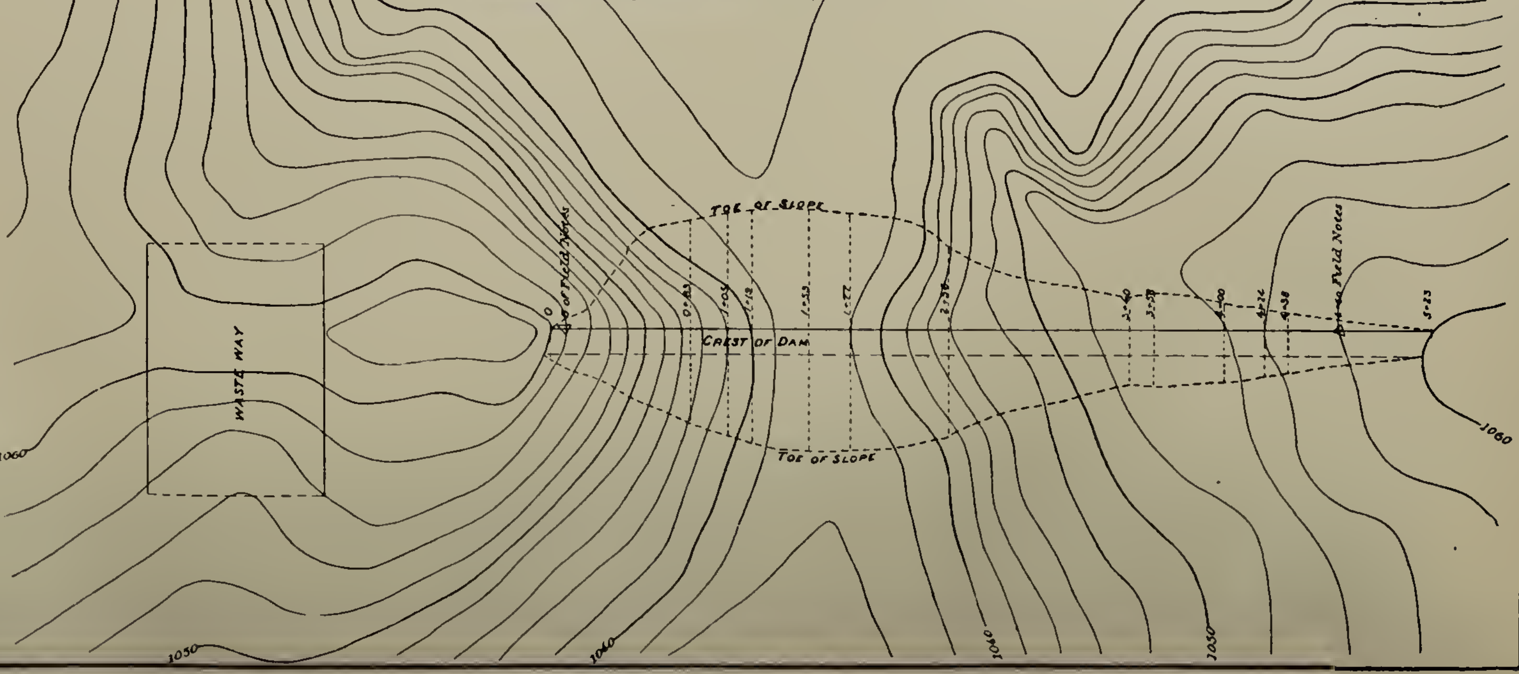




PLAN AND PROFILE OF DAM SITE

Maximum Height 23 Feet.
Length of Crest 523 Feet.
SCALE: 150 FEET - 1 INCH.

Contour Interval 2 ft.



Quantities of material and cost of construction.

[Reservoir capacity, 5,226 acre-feet.]

	Dam.	Wasteway.
Earth embankment, 303,840 cubic yards, at 25 cents	$75,960	
Masonry, 185 cubic yards, at $8		$1,480
Rock ballast, 550 cubic yards, at $1		550
12-inch paving, 2,470 square yards, at $1·25		3,087
10-inch paving, 1,000 square yards, at $1·10		1,100
6-inch paving, 29,832 square yards, at $1	29,832	
Gate tower and sluices	10,000	
	115,792	6,217
Total cost	122,009·00	
Plus 10 per cent for contingencies	135,210·00	
Cost per acre-foot stored	25·85	

Reservoir No. 8 is situated 1 mile north of Reservoir No. 7 and will be supplied from the same canal (Pl. CLXVI). It lies 110 feet higher than No. 7 and will drain into it through a natural water course. There is a small alkali lake in this basin flooding an area of 18 acres. The dam is to be constructed of earth and will be 523 feet long, 15 feet wide at the crest, which will rise 4 feet above the flood line. The greatest height will be 23 feet and the inner and outer slopes will be 1 on 3 and 1 on 2½, respectively, the former being paved with 6 inches of dry stone pitching.

It has been considered advisable to provide a wasteway for this dam of sufficient capacity to discharge the total volume of Canal No. 2, plus a little local drainage which it will catch. This wasteway is situated 150 feet south of the dam behind a low knoll, and discharges into a small drainage line by which the water will be led back into the main channel. It will be 150 feet long, 105 feet wide, and 4 feet deep, and will have masonry retaining walls on its sides, the bottom being paved.

Capacity of Reservoir No. 8.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1,044	11	71	602
1,048	13	85	891
1,052	17	102	1,287
1,056	21	122	1,735
1,060	25	150	2,278

Quantity of material and cost of construction.

[Reservoir capacity, 2,091 acre-feet.]

	Dam.	Wasteway.
Earth embankment, 12,224 cubic yards. at 20 cents	$2,445	
Masonry, 90 cubic yards, at $8		$720
Rock ballast, 405 cubic yards, at $1		405
10-inch paving, 1,815 square yards, at $1·15		2,087
8-inch paving, 1,165 square yards, at $1·10		1,281
6-inch paving, 2,154 square yards, at $1	2,154	
Gate tower and sluices	5,000	
	9,599	4,493
Total cost	14,092·00	
Plus 10 per cent for contingencies, total	15,501·00	
Cost per acre-foot stored	7·41	

In the above estimate no account is taken of the excavation for the foundations of the dam, as the material thus obtained can be used in the construction.

Reservoir No. 9 is a basin lying below Canal No. 2, from which it will be supplied (Pl. CLXVII). Although comparatively small it will have a sufficient capacity to irrigate all the good agricultural land below it. The dam will be constructed of earth and will be 481 feet long and 15 feet wide at the top. The greatest height of the dam will be 35 feet, while the flood line will be 4 feet lower. The inner and outer faces will have slopes of 1 on 3 and 1 on 2½, respectively, the inner face being covered with 6 inches of paving.

A wasteway will be unnecessary, as this reservoir is on the summit of a divide and has no local drainage, while it will be filled from a small canal taken from Canal No. 2, its source being thus under complete control.

Capacity of Reservoir No. 9.

Contour.	Available depth.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1,000	23	30	233
1,004	27	40	373
1,008	31	55	561
1,012	35	72	812

The quantities of material and cost of construction have been roughly estimated to be as follows:

Reservoir capacity acre-feet	727
Earth embankment, 31,987 cubic yards, at 25 cents	$7,997·00
Six-inch paving, 3,380 square yards, at $1	3,380·00
Gate tower and sluices	5,000·00
Total cost	16,377·00
Plus 10 per cent for contingencies, total	18,015·00
Cost per acre-foot stored	24·79

Reservoir No. 10, or Benton lake, is situated in the northeastern portion of T. 22 N., R. 3 E. It is about 1½ miles in width (Pl. CLXVIII). The lake is supplied by a very small intermittent stream known as Lake creek, which drains the catchment area of this basin, but has no natural outlet. It was the intention in making the survey in connection with the Sun river project to supply this reservoir from the Sun river by a long canal line. This idea, however, was afterwards abandoned and the canal line was dropped when within 15 miles of the lake, as it was found that the canal commanded more agricultural land than it could serve, superior in quality to that lying below the lake. This lake basin is drained by a cut 1¼ miles long, 35 feet in greatest depth, with side slopes of 1 on 1½. At flood level, the surface area is 9,130 acres and its available capacity above the bed of the cut is 140,200 acre-feet. The cut and outlet gates for converting Benton lake into a storage reser-

MONTANA

SUN RIVER RESERVOIR SYSTEM

RESERVOIR No 9.

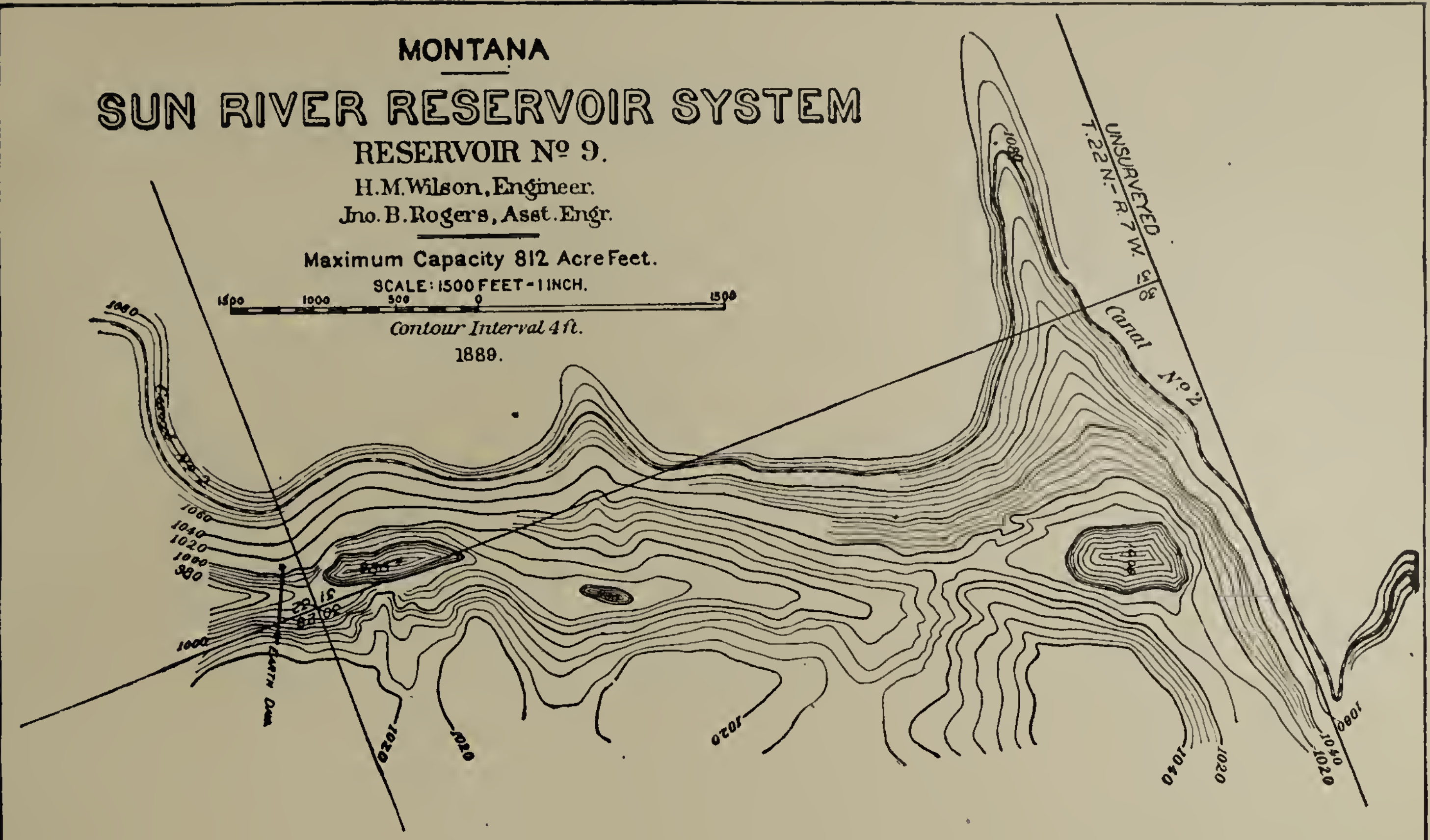
H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

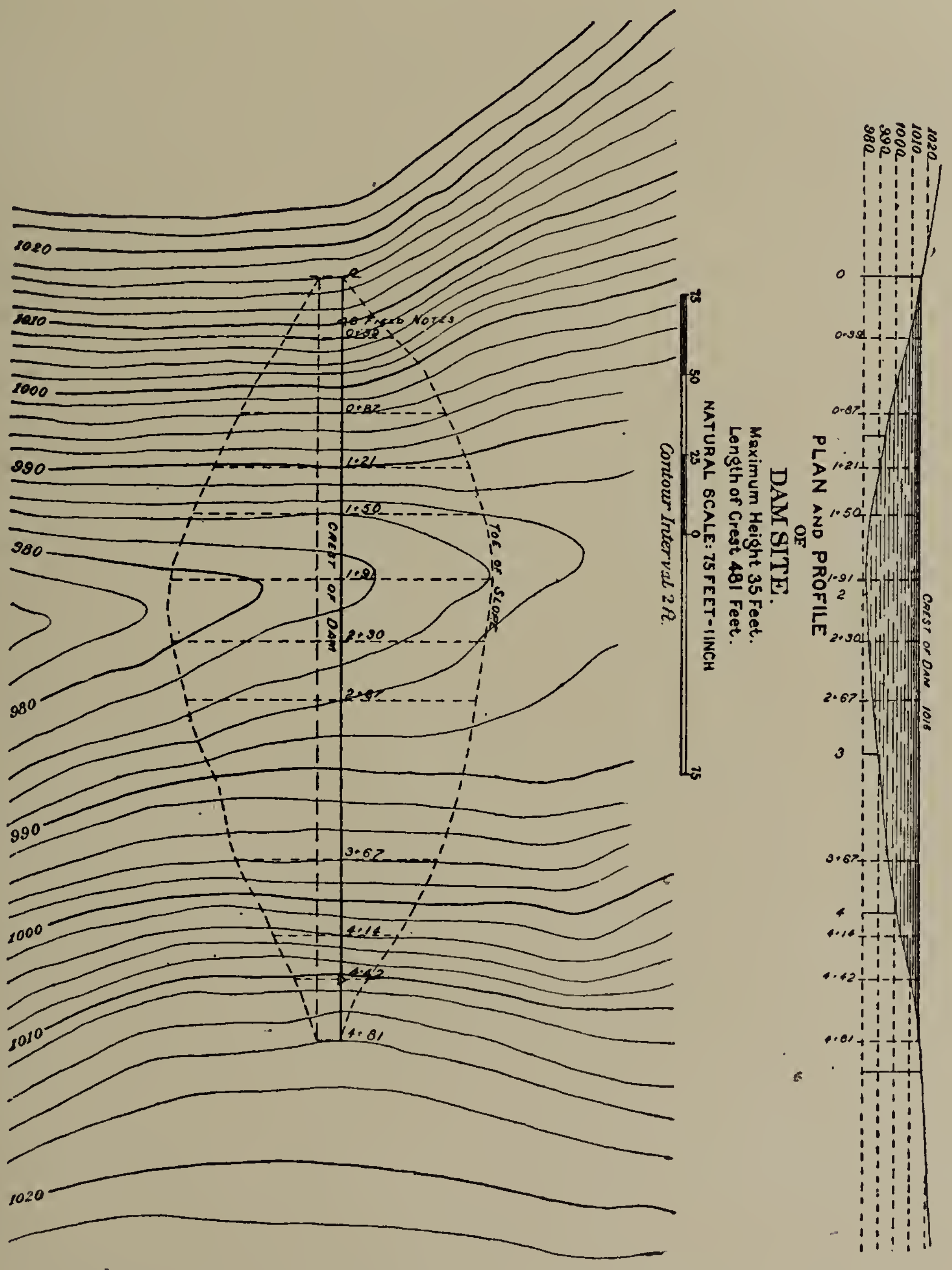
Maximum Capacity 812 Acre Feet.

SCALE: 1500 FEET-1 INCH.

Contour Interval 4 ft.

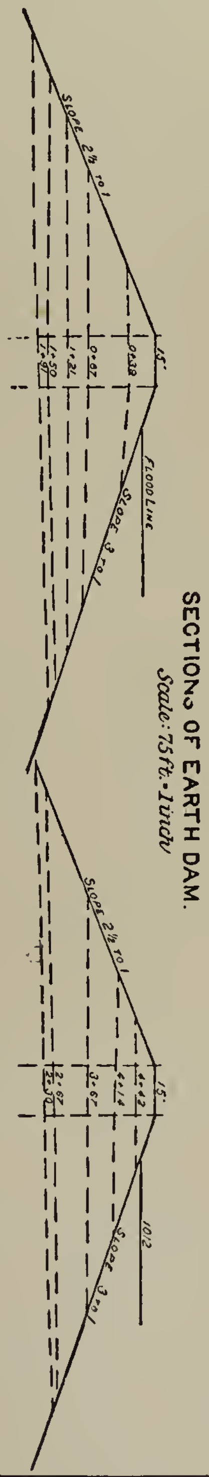
1889.





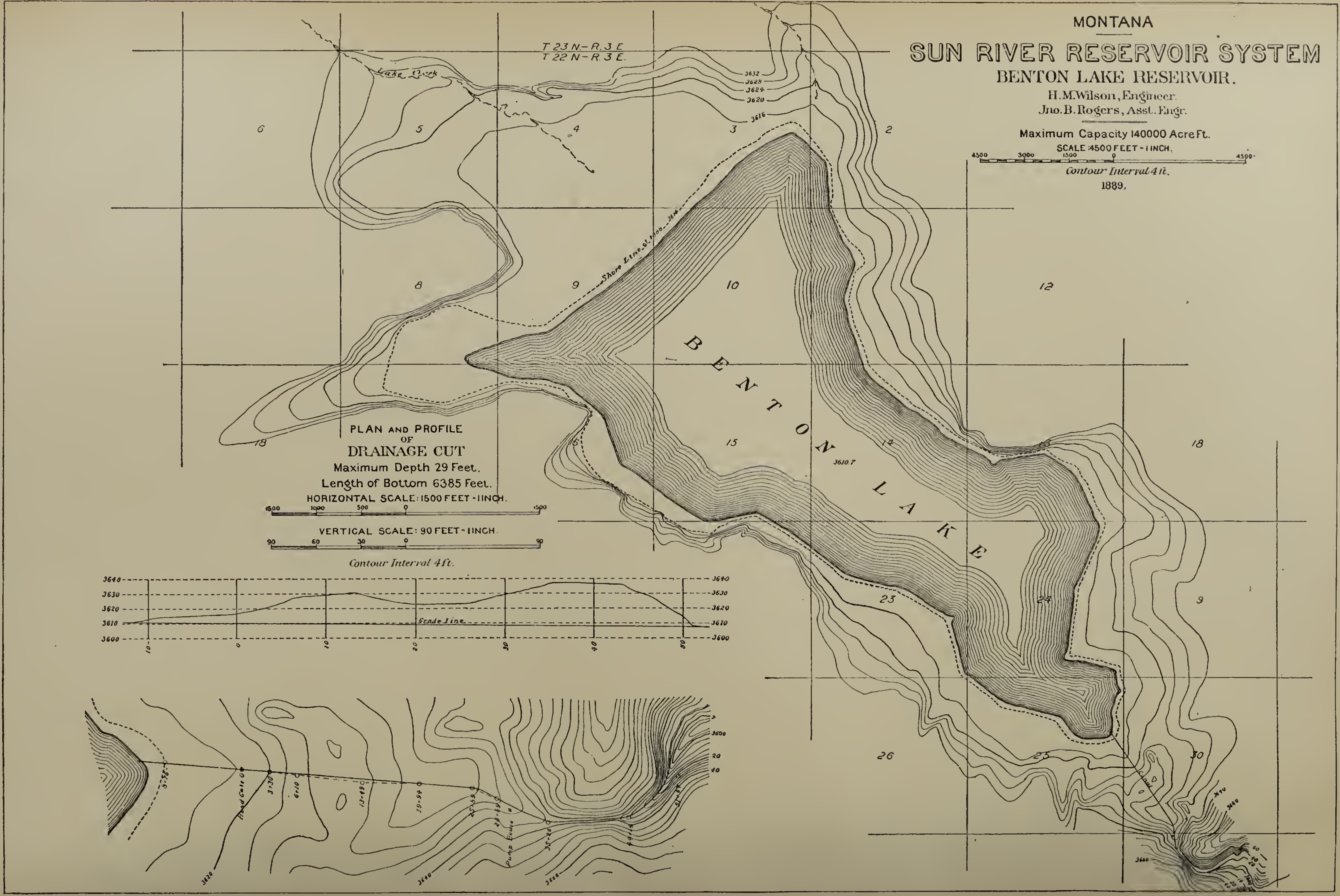
PLAN AND PROFILE OF DAM SITE.

Maximum Height 35 Feet.
Length of Crest 481 Feet.
NATURAL SCALE: 75 FEET-1 INCH.
Contour Interval 2 ft.



SECTIONS OF EARTH DAM.

Scale: 75 ft.-1 inch



MONTANA

SUN RIVER RESERVOIR SYSTEM

BENTON LAKE RESERVOIR.

H. M. Wilson, Engineer.
Jno. B. Rogers, Asst. Engr.

Maximum Capacity 140000 Acre Ft.
SCALE 4500 FEET = 1 INCH.
Contour Interval 4 ft.
1889.

PLAN AND PROFILE
OF
DRAINAGE CUT
Maximum Depth 29 Feet.
Length of Bottom 6385 Feet.
HORIZONTAL SCALE: 1500 FEET = 1 INCH.
VERTICAL SCALE: 90 FEET = 1 INCH.
Contour Interval 4 ft.

voir have already been constructed by private parties at a cost of about $145,000.

CANAL LINES.

Four canal lines were surveyed in connection with the Sun river project. Canal No. 1, the longest of these, is taken from the north side of Sun river in the NW. quarter of section 28, T. 22 N., R. 7 W., about 1 mile below reservoir No. 1. The river at this point is 160 feet wide and 4 feet deep, with gravel banks and small bowlder bottom and will require a weir 10 feet high for diverting the water into the canal head. The first 41 miles of the canal can properly be considered a diversion line, as for that distance it is located along a slope varying in steepness from 1 to 4 in 10. There are, however, some good bottom lands lying along the river below this line that could be irrigated by this canal at the end of the forty-first mile where the summit of the bench is reached, and from this point to the crossing of the Big Muddy creek it traverses excellent agricultural land sloping eastward with an average fall of 13 feet per mile. This canal was given a grade of 2 feet per mile, except on the bench lands when the grade was adapted to the slope of the country and given frequent drops of from 10 to 30 feet. This line was carried to the crossing of Big Muddy creek, a total distance of 66 miles, all of which will be in earth excavation. The water stored in reservoirs 1 to 4, amounting to 87,550 acre-feet after deducting losses by evaporation, can be utilized via canal No. 1, to irrigate the bench land north of the Sun river above Benton lake, or can be returned to the river for diversion to the 50,000 acres of land on the south side of the river between Fort Shaw and Cascade.

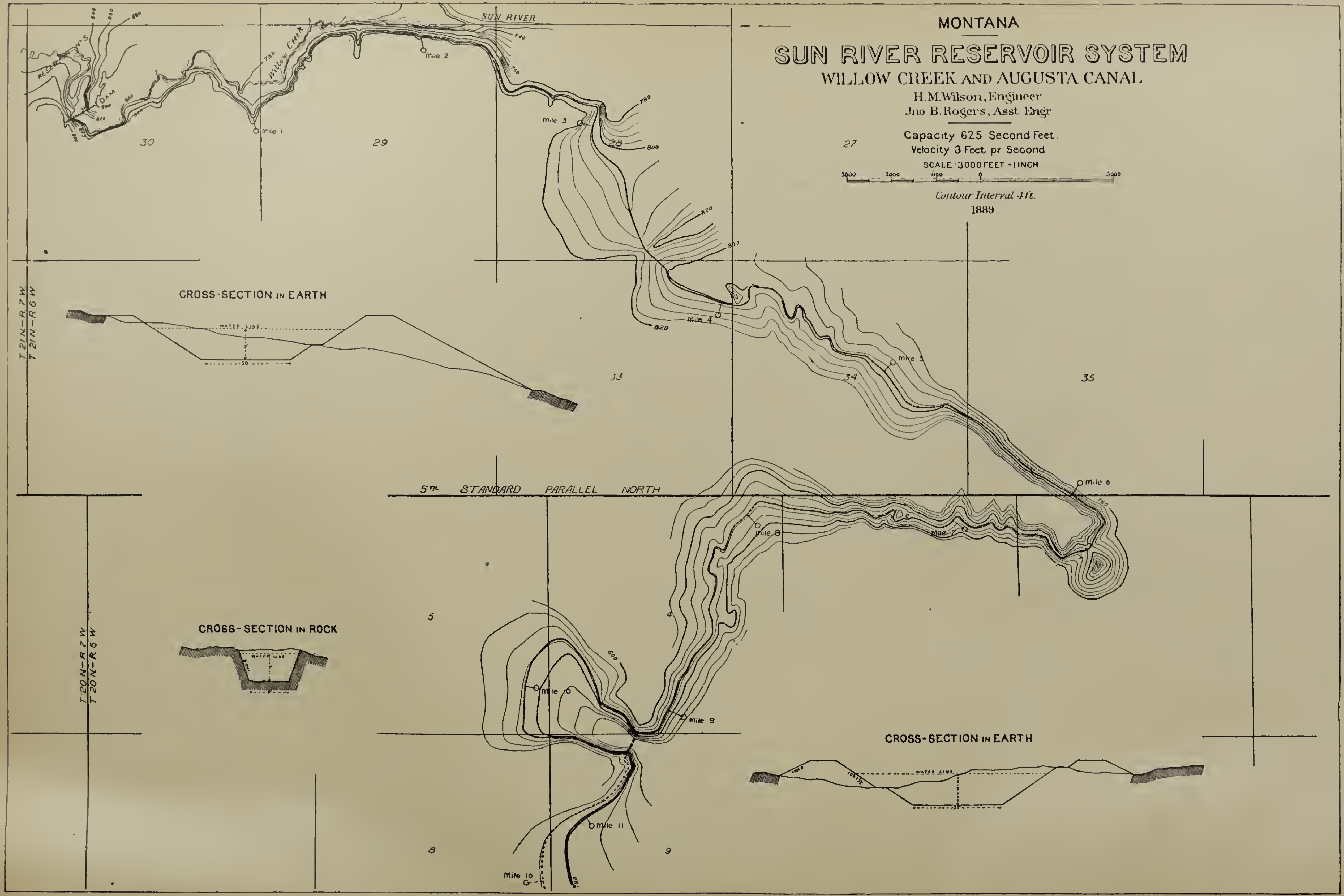
Canal No. 2 is taken from the top of reservoir No. 2 and will have its headworks in the wasteway of that reservoir. It is designed to carry the flood waters from reservoir No. 2 to supply reservoirs Nos. 5, 7, 8, and 9. The canal line is 13 miles in length and has a fall of 2½ feet per mile. With the exception of a few hundred feet it will be in earth excavation. Reservoir No. 9 lies parallel to and 64 feet below mile 10 of this canal line and is but a few hundred feet distant. This reservoir would be filled by a small lateral having a capacity of 20 second-feet, which is sufficient to fill it in twenty-one days, the time required to fill Nos. 5, 7, and 8. Canal No. 1 should be able to carry in sixty days this volume plus 50,000 acre-feet of perennial discharge, or in all 137,550 acre-feet, which is equivalent to 1,200 second-feet. Reservoirs 5, 4, 8, and 9 having a net storage capacity of 44,650 acre-feet may be filled via canal No. 2 from a portion of the remaining discharge of the North fork, and in order that this volume may be carried in twenty days canal No. 2 must have a capacity of 1,200 second-feet. The cross section designed for canals 1 and 2 in earth is 410 square feet, with a velocity of flow of 3 feet per second. The bottom width will be 37 feet, top width 70 feet, depth of water 8 feet, with a 4-foot berm and side slopes of 1 on 1½. In rock the dimensions will be, bottom width, 20 feet; depth of water, 8 feet; cross-sectional area, 136 square feet, with a velocity of flow of 7½ feet per second.

Canal No. 3 heads at the bottom of reservoir No. 5 at the dam site and will serve between 4,000 and 5,000 acres of good agricultural land lying below it between the north and south forks of Sun river. The line surveyed was 11¼ miles long and ended one-half mile east of the town of Augusta (Pl. CLXIX). This distance can be shortened 1¼ miles by carrying it across a 700-foot gap on a trestle 18 feet high. The first 3 miles of this canal will be considered as a division line and will be rather expensive work. The remainder of the line will be comparatively easy work and only earth excavation. It is the intention to carry this canal line across the South fork and down the south side of Sun river to cover a large area of good land lying on that side of the river. It was thought unnecessary to continue this survey as the fact that such a canal is feasible has been demonstrated by the Florence Canal company, which has constructed works in that locality. In order to carry off the water stored in reservoirs 5 to 8 in the shortest possible irrigating season of, say, 42 days, canal No. 3 should have a capacity of 625 second-feet, or a cross section of 208 square feet in earth with a velocity of 3 feet per second.

The fourth canal was surveyed by private parties. It will be diverted from the south bank of the Sun river above Fort Shaw and will serve about 50,000 acres on the point of land lying between the Sun river at Fort Shaw and Little Muddy creek. As shown later there will be available for this purpose about 36,000 acre-feet which will demand of the canal, in order to discharge it in 60 days, a capacity of 300 second-feet and with a velocity of 3 feet per second a cross section in earth of 100 square feet.

Preliminary estimate of cost of canals.

Canal No. 1:	
Diversion weir, 1,000 cubic yards loose rock, at $1·50	$1, 500
To forty-first mile, 3,736,620 cubic yards earth, at 10 cents	373, 662
To Muddy Creek, 968,880 cubic yards earth, at 10 cents	96, 820
	471, 982
Plus 10 per cent for contingencies, total	519, 180
If continued to Benton lake:	
15 miles canal, 506,880 cubic yards earth, at 10 cents	50, 688
Muddy Creek flume, 1,000 M. B. M. lumber, at $25	25, 000
	75, 688
Plus 10 per cent for contingencies, total	83, 257
Total cost to Benton lake	602, 437
Canal No. 2:	
Excavation 660,100 cubic yards earth, at 10 cents	66, 010
Excavation 9,000 cubic yards loose rock, at 40 cents	3, 600
Excavation 2,500 cubic yards blast rock, at $1	2, 500
	72, 110
Plus 10 per cent for contingencies, total	79, 321



MONTANA

SUN RIVER RESERVOIR SYSTEM

WILLOW CREEK AND AUGUSTA CANAL

H.M.Wilson, Engineer
Jno B. Rogers, Asst Engr

Capacity 625 Second Feet.
Velocity 3 Feet pr Second
SCALE 3000 FEET - 1 INCH

Contour Interval 4 ft.

1889.

Canal No. 3:

Excavation 312,560 cubic yards earth, at 10 cents	$31, 256
Excavation 1,000 cubic yards loose rock, at 40 cents	400
Excavation 1,500 cubic yards blast rock, at $1	1, 500
Headworks	1, 000
Flume	5, 000
	39, 156
Plus 10 per cent for contingencies	43, 072
Adding to the cost of Benton lake	145, 000
Cost of canal No. 1 below Muddy creek	83, 257
	*228, 257

Canal No. 4:

Diversion weir	5, 000
Excavation 580,000 cubic yards earth, at 10 cents	58, 000
	63, 000
Plus 10 per cent for contingencies	69, 300

AREAS OF LAND RECLAIMABLE.

The total amount of water available for irrigating the main bench land north of Sun river will be 137,550 acre-feet from the Sun river reservoirs, less 41,250 acre-feet, which is equivalent to a loss of 30 per cent by absorption in the canal, leaving 96,300 acre-feet which can be utilized to irrigate the bench above Benton lake.

In addition to this there will be 357,300 acre-feet available for storage in Benton lake, after deducting 35 per cent from the 396,000 acre-feet which may be diverted for this purpose. Since there are but 100,000 acres of good irrigable land below Benton lake and a supply for but 80 per cent is estimated as necessary in order to bring it under the highest state of cultivation, there will be use for and return from but 100,000 acre-feet of water. Hence 157,300 of the 257,300 acre-feet estimated as available for storage in Benton lake will have to be wasted or else storage found elsewhere for it.

The 800 acre-feet stored in reservoir No. 9 will irrigate about 1,000 acres of good land lying between it and the Sun river, and of the remaining 50,000 acre-feet stored in the Willow creek reservoirs 4,000 can be utilized to irrigate 5,000 acres of land along the line of canal No. 3 and above Augusta. No account need be taken of loss by absorption in canal No. 3, since the lands to be irrigated from it are immediately adjacent to it. The remaining 46,000 acre-feet may be permitted to flow down the Sun river, when, after allowing a loss of 30 per cent by absorption, it may be diverted above Fort Shaw to irrigate some of the 50,000 acres of land southeast of there. At a duty of 1¼ acre-feet per acre the 32,200 acre-feet reaching this land will irrigate 25,700 acres and will reclaim 32,100 acres.

---

[*] Which is the cost of storing 100,000 net acre-feet required in Benton lake, or $2·28 per acre-foot stored.

The 96,300 acre-feet available via canal No. 1 will in the same way irrigate 77,000 acres or reclaim 96,200 acres of the bench land above Benton lake.

In all, the water of the Sun river project as above utilized, will reclaim 96,200 acres above Benton lake; 100,000 acres below that lake; 1,200 acres below reservoir No. 9; 6,200 acres near Augusta and 32,100 acres below Fort Shaw, or a total of 235,700 acres of land. It will, however, derive a water rent from only 208,700 acres actually irrigated.

REVENUE.

At a water rate of $2 per annum per acre irrigated, 208,700 acres would return a gross annual revenue of $417,400 on the capital outlay. From this amount the cost of maintenance and repairs must be deducted, and roughly estimating this to be $150,000 per annum, the net receipts, $267,400, will pay 10 per cent interest on a total outlay of $2,674,000, without considering the first cost of a water right in perpetuity which should be worth at least $8 per acre, or in all $1,669,600. This deducted from the first cost of $2,186,456 leaves only $516,856 on which the annual water rate will have to pay interest.

Total estimated cost of the works.

	Total cost.	Cost per acre-foot.
Reservoir No.—		
1	$68, 902	$14·09
2	130, 958	10·06
3	253, 110	5·06
4	275, 495	14·05
5	166, 760	4·55
6	123, 375	20·29
7	135, 210	25·85
8	15, 501	7·41
9	18, 015	24·79
10	288, 257	2·28
Canal No.—		
1	519, 180	6·73
2	79, 321	2·88
3	43, 072	8·61
4	69, 300	2·71
Total	2, 186, 456	....

If all of these works were constructed as projected, it is evident that they would pay more than 10 per cent per annum on the estimated outlay of $2,186,456, when the country becomes well settled and there is a demand for all of the water provided.

There are several ways in which the cost of this project can be reduced, as a whole, the most prominent of which is by omitting the more expensive works, as reservoirs 6, 7, and 9, thus greatly reducing the average cost per acre-foot stored. Again, it is very likely that good storage sites may be formed on the South fork of Sun river, which may be constructed at relatively less cost, or some of the dams may be built higher than these designed.

If it is considered desirable to construct but a part of the works, reservoirs 2, 3, 5, and 8 and canals 2, 3, and 4, may be constructed and will yield proportionately large returns.

TRUCKEE AND CARSON RIVER SYSTEMS, NEVADA.

The Truckee and Carson river basins include within their areas some of the highest peaks of the Sierra Nevadas ranging in elevation from 10,000 to 13,000 feet in altitude. The precipitation on these, chiefly in the form of snow, is very heavy. In the lower portions of these basins are lesser ranges of mountains of comparatively barren aspect and having a relatively trifling precipitation on their watersheds. The lower courses of the Carson and Truckee rivers are through broad and comparatively level plains and deserts, the lowest of which is the Carson sink, but 3,880 feet above sea level.

The catchment basin of the Upper Truckee, above Verdi, at which point the river issues on to the Nevada plains, has an average elevation of about 7,500 feet and includes many lakes, large and small, which are supplied from the snow-clad peaks surrounding them. The slopes of this basin are extremely abrupt, but are generally well clothed with dense forests of pine, fir, and cedar trees.

In the neighborhood of Truckee on the lower drainage of the Donner, Prosser, and Little Truckee rivers are several beautiful and fertile valleys of considerable extent, containing much fine arable land; though the crops which can be cultivated here are only of the hardiest varieties, as the average elevation of these valleys is between 5,500 and 6,000 feet. Below Verdi and in the neighborhood of Washoe lake and Reno is a vast area of irrigable land, known as the Truckee meadows, of which about 15,000 acres are now irrigated. In addition to this the following lands are irrigated from the Upper Truckee system.

	Acres.
Prosser valley	3,000
Spanish springs valley	12,000
Lemmons valley	20,000
Warm springs valley	25,000
Total	60,000

Besides the above areas, there are about 5,000 acres irrigated on the Lower Truckee river and 30,000 acres of irrigable land east of Wadsworth on the Warm springs desert which can be reclaimed by water derived from the Truckee, above Wadsworth.

The Upper Carson basin differs from that of the Truckee in that it has fewer lakes and more large mountain valleys. The average elevation of its catchment basin is a little higher than that of the Truckee, while the mountain slopes are equally steep and abrupt and are clothed with dense forests. The irrigable lands commanded by the Carson river lie chiefly in the Upper Carson valley, above Genoa and Carson, through the center of which valley the river has an irregular course and is frequently divided into several streams or sloughs. This valley includes 25,000 acres of irrigated land and a large area of reclaimable land. In the neighborhood of Dayton are 1,500 acres and at Churchill and Lower Carson valleys 7,000 acres of irrigated land.

In addition to the area now under cultivation the following lands, situated on the Carson river, are irrigable from that stream:

	Acres.
Upper Carson valley	22,500
Dayton valley	15,500
Fort Churchill valley	15,000
Lower Carson desert	100,000
Total	153,000

No investigations have as yet been made to ascertain the duty of water in these valleys or in those of the Truckee, but it is probable that for some time to come it will not exceed 60 acres per second-foot. At present irrigation is extensively practiced, though in a small way and chiefly by individual irrigators. The result of the cultivation of these lands is highly satisfactory. The hardier fruits, such as berries, apples, and pears, yield abundant and excellent crops, and wheat, oats, hay, and potatoes are not only abundant in their yield, but unusually good in quality.

The rainfall over the area included within the drainage basins of the Truckee and Carson rivers is extremely variable, in spite of the fact that the area covered by these basins is not large. On the mountain watersheds of their upper tributaries the climatologic conditions are more like those on the California side of the Sierras. The precipitation on the Truckee meadows is 4·48 inches per annum. On the Lower Carson valley it is 7·43 inches, and on the Upper Carson valley it is 11·75 inches per annum. From river gaugings maintained by the hydrographers of the U. S. Geological Survey during portions of 1889 and 1890, the following gives the volumes of run-off of the catchment basins of the various reservoirs projected and available for storage:

	Acre-feet.
Upper Truckee reservoir	820,000
Donner and Cold creek reservoir	30,000
Independence lake reservoir	30,000
Webber lake reservoir	50,000
East Carson river, at Young's	840,000
Hope valley	130,000
West Carson river, at Woodford's	180,000

While there is a marked similarity between the topographic features of the Carson and Truckee river basins, decided contrasts are presented in studying the problem of irrigating the lands within these basins.

Though the basin of the Truckee is peculiarly favorable for the storage of water in natural lakes and valleys, the diversion of water from the river channel and its delivery to the irrigable lands presents numerous obstacles of construction which will render these canals expensive. On the other hand, the opportunities for water storage within the basin of the Carson river are much less unfavorable than those on the Truckee, but the diversion of water to the irrigable lands is relatively extremely simple, because these lands lie nearer the level of the river.

Surveys were made in the summer of 1889 to ascertain the most feasible and economic mode of utilizing the waters of these rivers and the results of the field examinations were worked up and reported to the U. S. Geological Survey by Mr. Wm. Ham Hall, supervising engineer. These surveys included the conversion of Tahoe, Donner, Independence, and Webber lakes into storage reservoirs besides the survey of other storage sites discovered and the discussion of the mode of diverting and utilizing the water so obtained. In a previous report was shown a general map of the Lahontan basin which includes the Carson and Truckee drainage basins.[1]

TRUCKEE RIVER BASIN.

DONNER LAKE RESERVOIR.

Donner lake occupies a glacial basin lying close under the main crest of the Sierra Nevada range and lengthwise between the spurs which jut out eastward from it. Ordinarily its water surface has a length of about 3 miles, a nearly uniform width of a little more than half a mile, and is at an elevation of about 6,095 feet above sea. It is 3 miles west of the town of Truckee and immediately north of and below the line of the Central Pacific railroad, where the ascent of the Sierra is made from the east.

The old glacial basin of Donner lake extends away eastward as a valley beyond the limits of the lake, and joins the Truckee river valley near the town of Truckee. Cold creek canyon enters the Donner valley three-fourths of a mile east of the east end of the lake, where it joins Donner creek, which flows thence eastward through the valley, from which it turns sharply to the south through a gap in one of the ancient moraines to join the river.

One project for the utilization of Donner basin contemplates the closing of this outlet gap by a high dam, and the closing of the main valley opening between the intermediate morainal ridge and the northern mountain spur by another dam, thus forming a reservoir covering the entire Donner valley and lake, and the opening of Cold creek valley. Another project contemplates the construction of a long, low dam. across the entire valley following the location of a later terminal moraine situated about half a mile from the lower end of the present lake.

---

[1] Eleventh Ann. Rept. U. S. Geol. Survey, pt. 2, 1889-'90, p. 152.

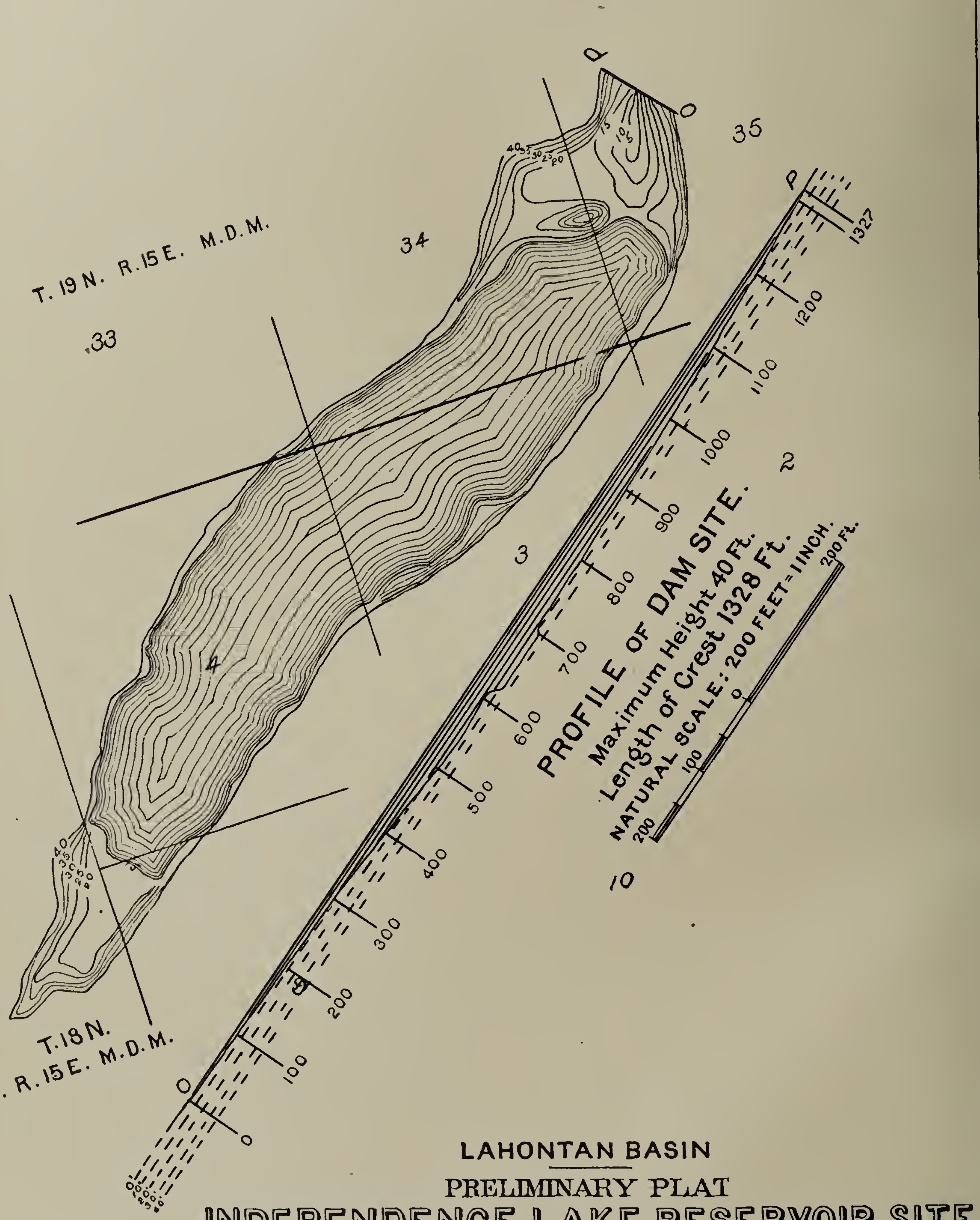
Plate CLXX shows a contour plan of the Donner lake and Cold creek valley reservoir site in outline, also the Truckee river site, together with the place on the line A–B of the plat, where it is proposed to erect a dam 3,021 feet long and 26 feet in maximum height for the storage of water in Donner lake basin alone. The plan also shows the places for two dams proposed for the storage of water in the Donner lake basin and the Cold creek valley combined, which will be 770 feet long and 98 feet in maximum height; the dam C–D, which will be 1,615 feet long and 33 feet in maximum height, and the dam on the line G–H across the Truckee river, whereby it is proposed to form the Truckee reservoir.

An estimate was made of the capacity of the Donner lake and Cold creek valley reservoir site above the base of the dam at E–F, giving at the 120-foot contour an area of 2,000 acres and a capacity of 42,827 acre-feet, and an estimate of the capacity of the Donner lake reservoir site as formed by the dam at A–B at the same elevation of the water plane above the same plane of reference, gives an area of 1,337 acres and contents of 22,005 acre-feet. Both these estimates of capacity are for the space above the low-water plane of Donner lake and do not allow for utilizing the lake basin proper by lowering its water surface.

The dimensions and capacities of the reserviors made by the various dams proposed and the dimensions of the dams are given in the following table:

Dam site.	Depth of water.	Area.	Capacity.
	Feet.	*Acres.*	*Acre-feet.*
No. 1. Reservoir above dam sites E–F and A–B (lake surface)	28	25	260
	53	115	1, 810
	178	1, 238	9, 600
	98	2, 006	42, 827
No. 2. Reservoir above dam A–B (lake surface)	16	1, 140	9, 776
	26	1, 337	22, 205

As surveyed, the dam for the Truckee reservoir, to the height of 46 feet above low-water plane in Donner lake, would be 1,131 feet in length and 70 feet in height above the bed of the Truckee river where crossed. As demonstrated by this survey, water would be backed by this dam up Truckee canyon about 2·31 miles to a maximum width of 1,500 feet and would cover 206 acres of area. This reservoir would be formed by the construction of a dam marked G–H on the plat, and was intended to be an adjunct of that reservoir. The chief waters which it would impound would be those discharged by the main Truckee river. The expediency of building it is a little doubtful, as the work performed by it may be done by the employment of Lake Tahoe as a storage basin. The Truckee reservoir site, however, has a great advantage over Lake Tahoe in that it exposes to evaporation an infinitely smaller surface and if it is shown by further investigation to be necessary to conserve the waters of the main Truckee, this will probably prove the most economical reservoir site for that purpose.



LAHONTAN BASIN

PRELIMINARY PLAT

INDEPENDENCE LAKE RESERVOIR SITE

Wm. Ham. Hall, Supervising Engr.
Lyman Bridges, Engineer.

Maximum Capacity 23707 Acre-Ft.

SCALE: 2 INCHES = 1 MILE.

1 3/4 1/2 1/4 0 1 MILE

Contour Interval 5 ft.

1889.

Preliminary estimate of the quantities of material for and cost of constructing the Donner lake reservoirs.

Capacity, Reservoir No. 1 . . . . acre-feet . .	42, 827
Loose rock in dam, E–F, 80,618 cubic yards, at $2	$161, 236·00
Foundation in dam, E–F	3, 500·00
Lumber, 200 M. B. M., at $30	6, 000·00
Earth in dam, C–D, 154,957 cubic yards, at 30 cents	46, 487·00
Paving face of dam, C–D	8, 000·00
Wasteway	8, 000·00
Gate tower, etc	25, 000·00
	258, 223·00
Plus 10 per cent for contingencies, total	279, 245·00
Cost per acre foot stored	6·52
Capacity, Reservoir No. 2 . . . . acre-feet . .	22, 205
Earth embankment, 89,420 cubic yards, at 30 cents	$26, 826·00
Wasteway	8, 000·00
Paving face of dam	5, 000·00
Gate tower, etc	10, 000·00
	49, 826·00
Plus 10 per cent for contingencies, total	54, 810·00
Cost, per acre-foot, stored	2·86

INDEPENDENCE LAKE RESERVOIR.

Independence lake is a counterpart of Donner, of glacial origin, immediately under the crest of the Sierras and held lengthwise between high mountain spurs jutting out at right angles thereto (Pl. CLXXI). The natural dam between these spurs forms the lake, and is plainly an old moraine. It lies 9 miles, in a direct line, a little north of west from Donner and is about 6,997 feet above sea level. Its waters escape by Independence creek, turn northward, and become tributary to the Little Truckee, a main branch of the Truckee river. The dam site was chosen at a comparatively narrow part of the outlet valley, 1,800 feet beyond the end of the lake and where the bed of the outlet creek was 12 feet below the water surface of the lake.

In the following table is given the area exposed to evaporation and the capacity of Independence lake reservoir for several different elevations:

Depth of water (lake surface).	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
15	709	1, 848
25	874	9, 850
40	984	23, 707

The dam, at the elevation of 40 feet above the base and 25 feet above the plane of the lake water, will be 1,328 feet in length. The following is a preliminary estimate of the quantities of material and cost of constructing this reservoir:

[Reservoir capacity, 23,707 acre-feet.]

	Loose rock.	Earth.
Rock, 27,480 cubic yards, at $2·25	$61, 830	....
Lumber, 100 M., B. M., at $30	3, 000	....
Earth, 79,190 cubic yards, at 40 cents	....	$31, 676
Paving	....	44, 000
Gate tower	10, 000	10, 000
Wasteway	6, 000	6, 000
	80, 830	51, 676
Plus 10 per cent for contingencies	88, 913	56, 844
Cost per acre-foot stored	3 ·75	2 ·40

WEBBER LAKE RESERVOIR.

About 7 miles north of west from Independence lake, in the summit valley of the famous Henness pass over the Sierra Nevada range, at an elevation of about 6,769 feet above the sea, lies Webber lake, bordered by a flat, grass-grown meadow (Pl. CLXXII). The Little Truckee river rises west of the main range behind Independence lake, flows north about 10 miles into Webber lake and departing thence breaks through the main range eastwardly. A short distance below the lake the canyon narrows. Surveys were made to study this location for reservoir purposes. The following capacities have been estimated for this reservoir to a height of 20 feet above the surface of the lake.

Depth of water (lake surface).	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
10	247	621
20	542	4, 540
30	778	11, 152

The dam site projected is in the canyon opening, about 1,200 feet from the lower end of the lake. The dam will be 30 feet in maximum height and 812 feet in length on the crest.

Preliminary estimate of the quantities and cost of material of the Webber reservoir.

[Reservoir capacity, 11,152 acre-feet.]

	Loose rock.	Earth.
Rock, 11,875 cubic yards, at $2·25	$26, 720	....
Lumber, 60 M. B. M., at $30	1, 800	....
Earth, 29,175 cubic yards, at 30 cents	....	$8, 752
Paving	....	2, 000
Gate tower, etc	6, 000	6, 000
Wasteway	5, 000	5, 000
	39, 520	21, 752
Plus 10 per cent for contingencies	43, 472	23, 927
Cost per acre-foot stored	3 ·90	2 ·14

LAHONTAN BASIN

PRELIMINARY PLAT

WEBBER LAKE RESERVOIR SITE.

Wm. Ham. Hall, Superv.g Engr.
Lyman Bridges, Engineer

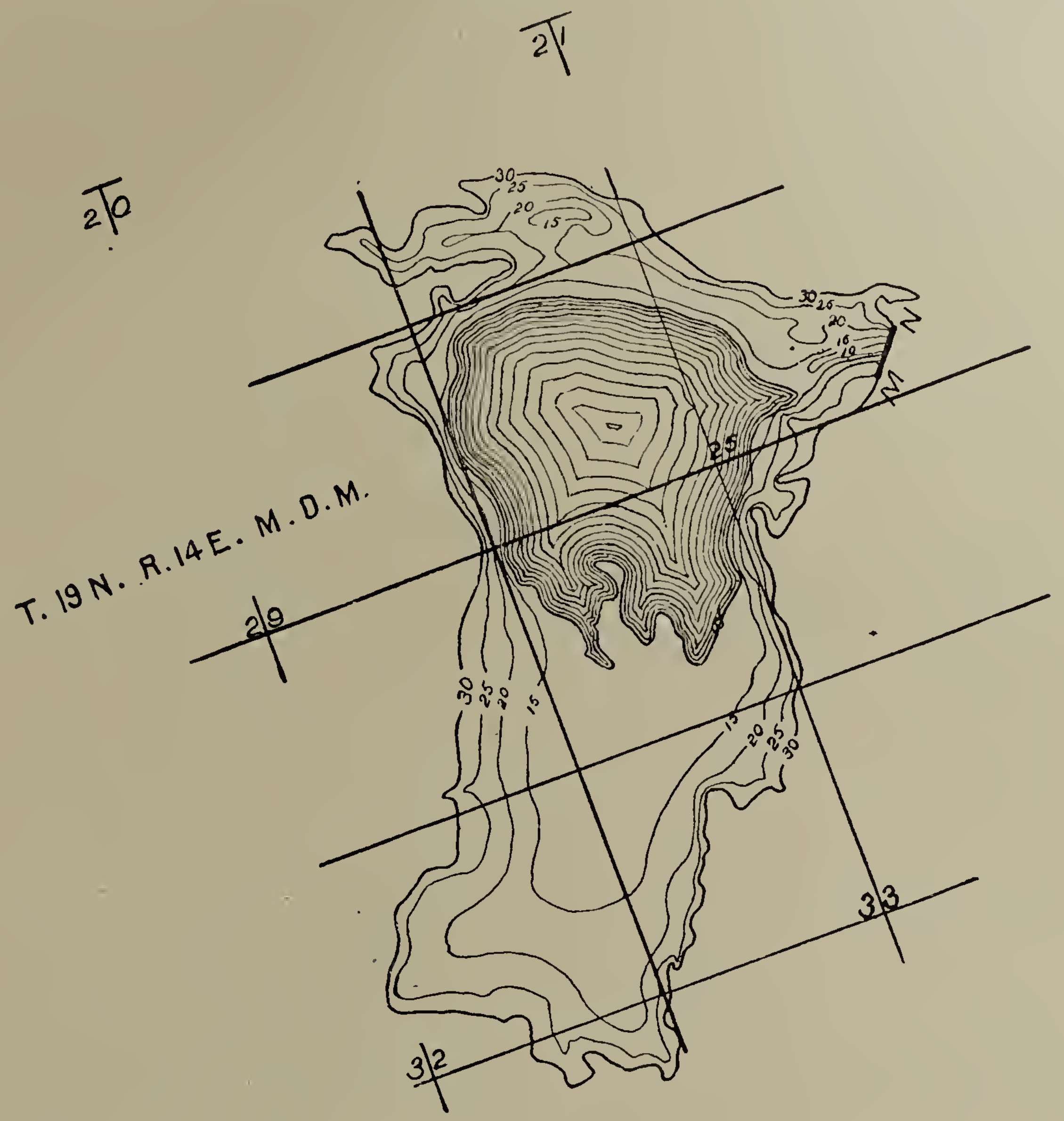
Maximum Capacity 11152 Acre Ft.

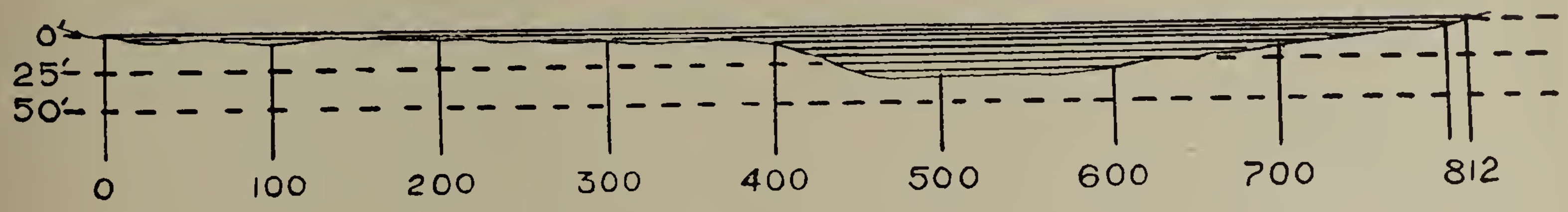
SCALE: 2 INCHES = 1 MILE.

1 3/4 1/2 1/4 0 1 MILE.

Contour Interval 5 feet.

1889





PROFILE OF DAM SITE.

Maximum Height 29 Ft.
Length of Crest 812 Feet.

NATURAL SCALE: 150 FEET = 1 INCH.

150 100 50 0 150 FT.

LOWER TRUCKEE CANALS.

Surveys were made for canals to divert the waters of the Truckee to the lands along the upper portion of the river in the neighborhood of the Truckee meadows. From these it appears that the water can be easily and cheaply led on to these lands without incurring any appreciable expense for diversion weirs or canals. Accordingly no estimate has been made of the cost of these works.

Surveys were made along the lower portions of the Truckee for diversion of the water to the plains north and east of Wadsworth. From there it was found that the river flows in a canyon from 100 to 200 feet in depth, and that considerable expense will be incurred in diverting the water, both for the construction of the weir and the canals.

The lower dam site is located 4¾ miles above Wadsworth on the Big bend of Truckee river. The crest line which extends across from the grade of the Central Pacific railroad to a point of rocks opposite O'Brien's will be about 1,000 feet long, with a maximum height of 63 feet above the bed of the river.

A canal line was surveyed from the south end of the dam at an elevation 15 feet below its top, and was extended to a total length of 50,700 feet to the commencement of Warm spring valley, 5½ miles below Wadsworth. The upper dam site is 5¾ miles above that at O'Brien's and 3·3 miles below Clark's station on the Central Pacific railroad. The length of the dam is 870 feet, the height above the river bed 50 feet, and its height above the top of the projected dam at O'Brien's is 90 feet. This line was located along the mountain face which comes abruptly to the river on the south side.

It commands 10,500 acres of good land between Wadsworth and Ragtown pass. The canal was given a cross section of 40 square feet and a grade of 0·2 per 1,000, thus making its capacity second-feet; sufficient to irrigate 7,500 acres in ninety days.

A canal line was run commencing a few feet below the crest of the dam and followed the mountain side south of the river, to a point just above Wadsworth, and thence swung around to the south, commanding a wide valley and mesa country east of the town above named. It was continued a distance of 90,000 feet, sufficiently far to establish the fact that it could be carried over a divide known as Ragtown pass, to deliver water in an arm of Lower Carson valley. From the main line a branch was taken off just below the O'Brien dam site with the object of crossing the river by pressure pipes. This line was carried thence a distance of 45,000 feet on a grade of 1 foot per mile, to command lands on the high plateau north of Wadsworth.

The main canal will command 13,000 acres of good, arable land between Wadsworth and Ragtown pass, and 100,000 acres east of the pass in the Lower Carson valley. It was given a grade of 1·5 feet per mile and a cross section of 200 square feet, making its capacity 600 second-feet or sufficient to irrigate 30,000 acres in ninety days.

The following preliminary estimate gives the relative cost of the two canal projects outlined above:

Lower canal.

O'Brien's rock dam, 47,000 cubic yards, at $2	$94, 000 ·00
Lumber, 260 M, B. M., at $35	9, 100 ·00
Wasteway	5, 000 ·00
Canal, loose rock, 36,000 cubic yards, at 40 cents	14, 400 ·00
Canal, blast rock, 20,000 cubic yards, at $1·25	25, 000 ·00
Canal, earth, 44,000 cubic yards, at 15 cents	4, 600 ·00
6 trestles and flumes	15, 000 ·00
Total cost	167, 100 ·00
Plus 10 per cent for contingencies	183, 800 ·00
Cost per acre irrigable	24 ·50

Upper canal.

Clark's rock dam, 16,600 cubic yards, at $2	33, 200 ·00
Lumber, 140 M. B. M., at $35	4, 900 ·00
Wasteway	5, 000 ·00
Canal, loose rock, 60,000 cubic yards, at 40 cents	24, 000 ·00
Canal, blast rock, 30,000 cubic yards, at $1·25	37, 500 ·00
Canal, earth, 55,000 cubic yards, at 15 cents	8, 200 ·00
7 trestles and flumes	18, 000 ·00
Total cost	130, 800 ·00
Plus 10 per cent for contingencies	144, 600 ·00
Cost per acre irrigable	4 ·82

From the above it is very evident that the Clark's or upper site is not only far preferable to the lower one, but a canal taken from that point will utilize all the waters of the Truckee reaching there and will doubtless prove a remunerative investment. No estimate is included here, however, of the cost of changing the line of the Central Pacific railroad. This will be very expensive work.

CARSON RIVER BASIN.

LONG VALLEY RESERVOIR.

This site consists of two valleys side by side and separated by a low ridge (Pl. CLXXIII). A canyon holding a stream bed escapes from each, consequently it will be necessary to build two dams, one to close each canyon opening. The easternmost of these twin valleys is Long valley proper; the westernmost is Springmeyer valley. Cross sections of the canyons at the proposed dam sites were surveyed; the top contour of the proposed reservoir space was meandered and the valleys cross sectioned.

The dimensions of the dams proposed, with the estimates of the quantity of material required in their construction and the capacities for various heights above their bases, are given in the tables following:

Long Valley reservoir site, above main dam.

Length.	Depth of water.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
794	50	138	1, 635
	60	388	4, 270
	80	525	12, 834
	100	688	24, 300

Springmeyer's reservoir site.

1, 510	20	129	680
	40	257	4, 488
	60	398	10, 125

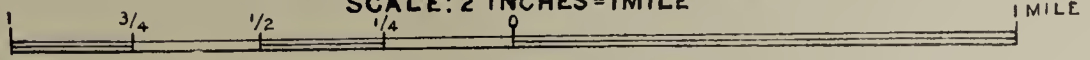
LAHONTAN BASIN

PRELIMINARY PLAT

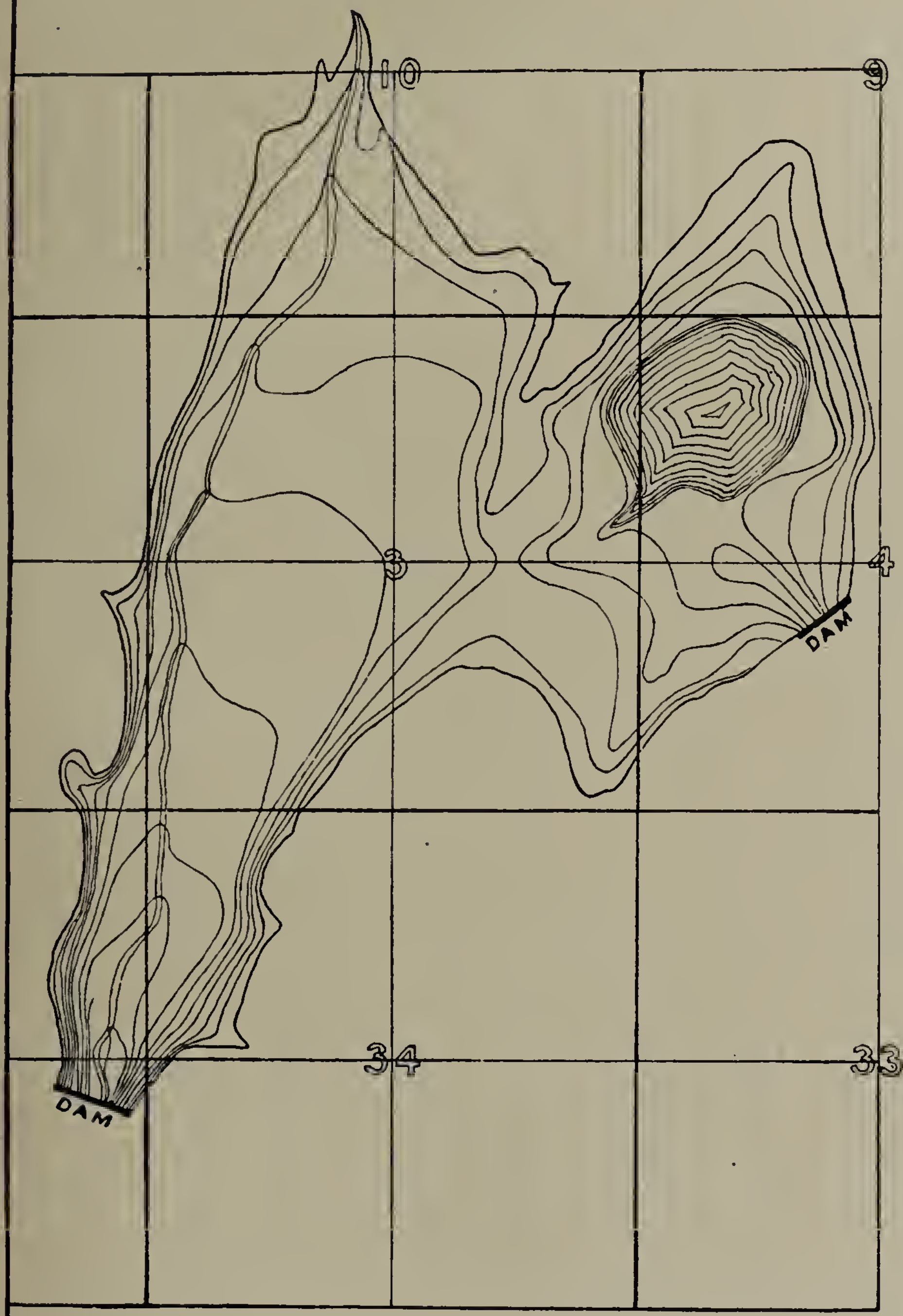
LONG VALLEY RESERVOIR SITE

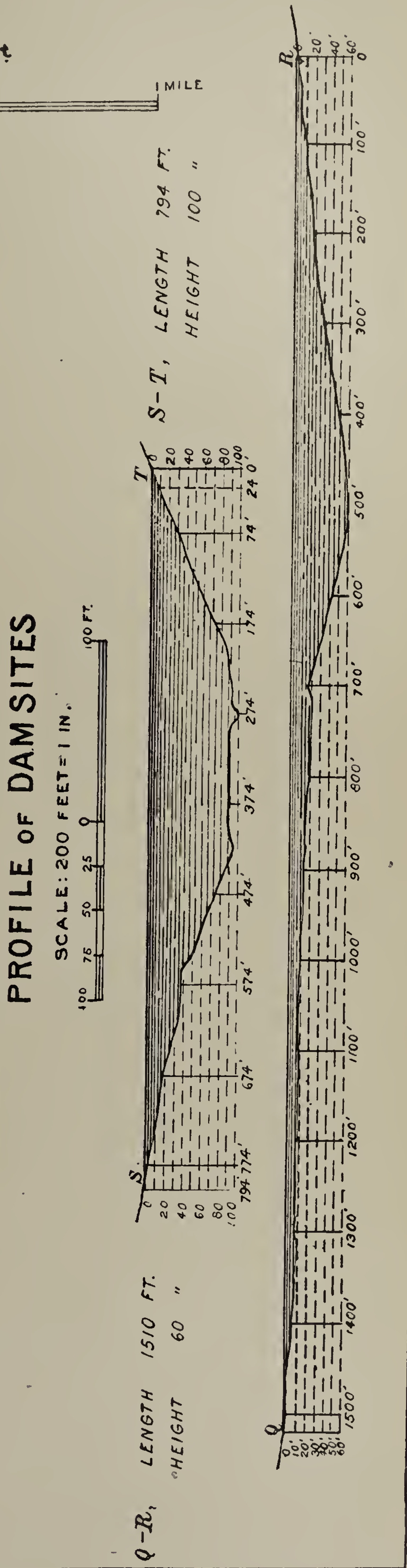
Wm. Ham. Hall, Supervising Eng^{r}
Lyman Bridges, Engineer

Maximum Capacity 34,425 Acre Ft.
SCALE: 2 INCHES = 1 MILE



Contour Interval 10 ft.
1889





Total capacity, Long Valley reservoir site.

Depth of water on main dam.	Area.	Capacity.
Feet.	*Acres.*	*Acre-feet.*
80	782	15,686
100	1,086	34,425

Preliminary estimate of the quantities of material and cost of the proposed Long valley and Springmeyer reservoirs.

Long valley Dam:	
Combined reservoir capacity ... acre-feet	34,425·00
Loose rock, 101,750 cubic yards, at $2	$203,500·00
Lumber, 220 M., B. M., at $35	7,700·00
Gate tower, etc	30,000·00
Foundation, 9,000 cubic yards, at 40 cents	3,600·00
Total cost	244,800·00
Plus 10 per cent for contingencies	269,300·00
Springmeyer's Dam:	
Earth, 92,380 cubic yards, at 40 cents	36,950·00
8-inch paving, 5,000 square yards, at $1	5,000·00
Wasteway	5,000·00
Gate tower, etc	20,000·00
Total cost	66,950·00
Plus 10 per cent for contingencies	73,640·00
Total cost combined reservoir	342,940·00
Cost per acre-foot stored	9·96

Several surveys were made for the purpose of ascertaining the most feasible canal line for supplying water to fill the Long valley reservoirs, both by diversion from the East and West forks of the Carson river. In addition to these, other canal surveys were made to discover the best mode of delivering the storage waters to the irrigable lands between the forks, and to "Twelvemile desert." The cost of the latter projects need not be considered, as the waters may be permitted to flow by natural channels to the irrigable lands in the Carson valley, where the cost of diversion will be trifling.

The supply canal from the East fork will require a diverting weir at its head 431 feet long and 98 feet in maximum height, the canal itself being 6,300 feet in length, of which 1,150 feet would be a tunnel through soft rock. This project would double the cost of storing the water and raise it to about $20 per acre-foot.

The supply canal from the West fork would head about 1 mile above Woodfords, where a diversion weir 458 feet long and 20 feet high would have to be constructed. The canal would be 5 miles long. This project will increase the cost of storing water in Long valley reservoir to at least $15 per acre-foot.

HOPE VALLEY RESERVOIR SURVEY.

Hope valley commences about 10 miles from the southern end of Lake Tahoe, at an elevation of 7,050 feet above the sea and extends nearly 10 miles. It is separated into two somewhat distinct parts by a low, rocky ridge lying across the general direction of the valley (Pl. CLXXIV).

The lower division of this great depression is known as Hope valley; the upper division as Faith valley. The waters of the West Carson river drain from the mountains above and around these valleys. The main channel winds northerly and longitudinally through them and near the north end of Hope valley turns abruptly to the east and plunges headlong through a deep, rocky canyon down to the main valley.

Detailed surveys were made of the site of the proposed dam and estimates of volume of the dam and of the capacity of the reservoir for different elevations of the water plane above its base. The following table gives the capacity of this reservoir for various depths of water:

Length.	Depth of water.	Area.	Capacity.
Feet.	*Feet.*	*Acres.*	*Acre-feet.*
1,560	123	1,081	18,215
....	143	1,595	60,905
....	163	1,803	94,810

A preliminary estimate has been made of the quantities of material required and cost of the above dam, with the following results:

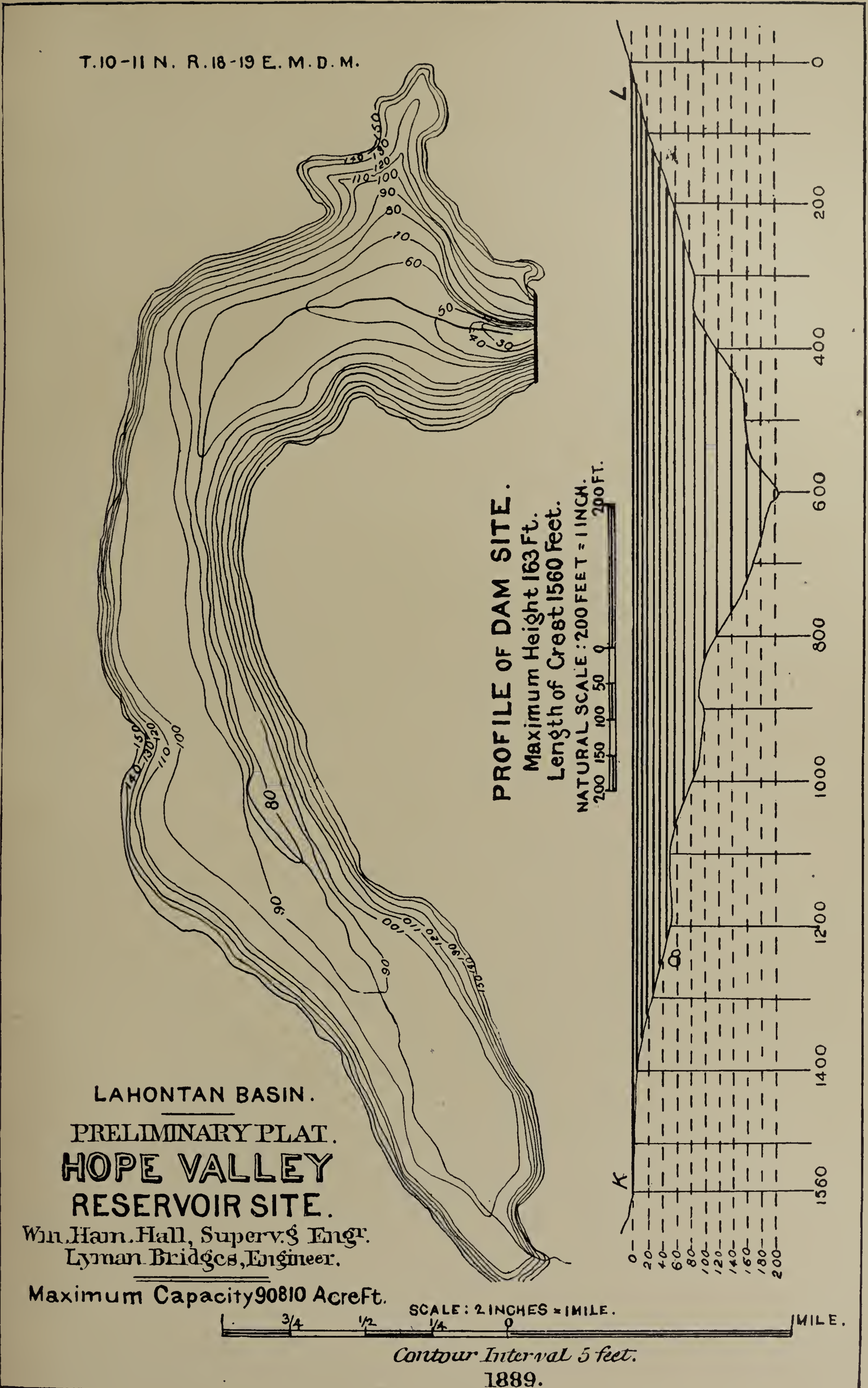
[Reservoir capacity, 94,810 acre-feet.]

	Masonry dam.	Rock-filled dam.
Rubble masonry, 205,720 cubic yards at $10	$2,057,200·00	....
Loose rock, 444,560 cubic yards, at $2·25	....	$1,260,000·00
Lumber, 765 M., B. M., at $30	....	22,950·00
Gate tower, outlet sluices, etc	5,000·00	30,000·00
Wasteway	5,000·00	5,000·00
Excavation foundation, 190,000 cubic yards, at $1	....	190,000·00
Excavation foundation, 100,000 cubic yards, at $1	100,000·00	....
Total cost	2,167,200·00	1,507,950·00
Plus 10 per cent for contingencies	2,383,900·00	1,658,700·00
Cost per acre-foot, stored	25·15	17·50

From the above it appears probable that this reservoir will not prove a paying investment if constructed, as its cost is so high as to be almost prohibitive.

It will be understood that the numerical results submitted above are approximations of the actual facts. The contour sketches of the sites have been made up without fully platting the survey meander notes, in some instances relying almost wholly upon the cross-section level notes of the sites. Moreover, the plats are drawn to a scale too small from which to make close estimates of the areas held within the several contours, and consequently the estimates of capacity of the reservoir spaces may well be 5 and possibly 7 or 8 per cent in error.

The estimates of quantities in the proposed dams are based upon a study of only one section of the canyon at each site; indeed, in most instances there was only one section surveyed. Hence these estimated



LAHONTAN BASIN.

PRELIMINARY PLAT.

HOPE VALLEY

RESERVOIR SITE.

Wm. Ham. Hall, Superv. & Engr.
Lyman Bridges, Engineer.

Maximum Capacity 90810 Acre Ft.

Contour Interval 5 feet.

1889.

quantities also may be and probably are 5 to 10 per cent in error; but the endeavor has been to make these estimates sufficiently great, so that any correction of the future will probably be in the way of reducing the volumes estimated for the dams.

From the previous discussion of the discharges of the various streams from which the reservoirs surveyed must be filled, it is evident that in such a year as 1890 the volumes available for storage were more than sufficient to fill the reservoirs. In an exceptionally dry year, like 1889, however, the run-off from their catchment basins was scarcely sufficient to fill Independence, Donner, and Hope reservoirs, though it would be sufficient to fill the others. The quantity of water available for irrigation from the various reservoirs must be diminished by the amount of evaporation estimated to occur from their surfaces—this will be equivalent to a depth of 2½ feet over the area exposed. Making the deductions for loss by evaporation, the Donner and Cold creek reservoirs, above dam site E–F, will have the net storage capacity of 37,810 feet. Above dam site A–B, its net storage capacity will be 18,865 acre-feet. In like manner the net available storage capacity of Independence reservoir will be 21,247 acre-feet; that of Webber lake will be 9,207 acre-feet; that of Long valley will be 31,710 acre-feet; and that of Hope valley will be 90,300 acre-feet.

At the same rates Independence and Webber lakes will supply sufficient water to irrigate over 15,300 acres of the arable land in the Little Truckee valley. As there are but 3,700 acres of this, there will remain from this source sufficient water to irrigate 11,600 acres, which may be passed down the Truckee river and be diverted to irrigate the Truckee meadows and neighboring valleys. Donner and Cold creek reservoirs will at similar rates furnish sufficient water to irrigate about 27,600 acres in the Upper Truckee valleys.

These valleys have an area of about 60,000 acres, for which there will be a sufficient water supply to irrigate 39,200 acres, as above shown, being surplus from Webber and Donner lakes. The remaining land will have to be supplied from water provided by the perennial discharge of the Truckee river, or other storage sites in the Upper Truckee or in Lake Tahoe. The maximum perennial discharge of the Truckee river at Vista, a short distance above Reno, during the growing season, from April to August, inclusive, is not less than 1,000 second-feet, which, at a duty of 60 acres per second-foot, would irrigate 60,000 acres. Apparently there is sufficient water from this source to irrigate all the best lands otherwise unprovided for on this stream.

Hope and Long valley reservoirs combined will, at a duty of three-fourths of an acre per acre-foot, irrigate 91,500 acres of the 153,000 acres of arable land which are available in Upper and Lower Carson valleys. As but three-fourths of the area available is the most which is liable to be irrigated at any given period, it is probable that the above available quantity of water will cover the larger part of the lands in these valleys.

CALIFORNIA DIVISION.

The work of this division was under the general supervision of Mr. William Ham Hall. The definite surveys made were prosecuted in two portions of the state and consisted of preliminary surveys of seven reservoir sites in the high Sierras at the heads of the Tuolumne, Merced, and Stanislaus rivers, and of a detailed survey of Clear lake in the Coast range. The mountain survey party had in view the discovery and location of reservoir sites in which the flood waters from the higher peaks of the Sierras might be stored so that it could be turned back into the waterways and permitted to run down these to the San Joaquin valley. The Clear lake survey consisted chiefly of hydrographic and topographic examinations and in determining the area of the lake exposed to evaporation. As a consequence of the fact that the inflow to the lake was small its utility as a reservoir site was a matter of doubt, depending chiefly on the relation between the areas exposed to evaporation and percolation and the water supply furnished by its catchment basin.

HIGH SIERRA RESERVOIRS.

The topography of the region in which the mountain reservoir surveys were made shows a vast diversity not only in its physical features but in its climatology. The land to be irrigated, lies on the east side of the San Joaquin valley where the country is nearly level and the climate quite arid. The elevation of the plain at the immediate foothills ranges between 150 and 200 feet and it slopes thence westward toward the San Joaquin river with a grade of about 10 feet to the mile.

From the axial point at the junction of the foothills with the San Joaquin valley the mountains rise to the east through three various zones which are well marked equally by the topography and the forestry. From the valley edge at an elevation of nearly 200 feet above sea level the rise eastward for a distance of from 20 to 25 miles is through a series of broken and irregular hills arranged like steps and separated by valleys the general trend of which is northwest and southeast. This belt of foothills ranges from an altitude of 800 to 2,000 feet near the valley edge to an altitude of 4,000 to 5,000 feet at the eastern edge.

The second great topographic feature consists of a more regular and uniformly sloping country, extending from the foot of the great peaks of the high Sierras with an easy incline to the westward to the country just described. This region has few prominent hills, being practically a great inclined table-land through which are cut deep canyons in which flow the streams at a depth of several thousand feet beneath the surface level. To the east of this region is the third and last topographic division, the high Sierras proper, extending from the upper level of the table land just mentioned at an elevation of 6,000 to 7,000 feet eastward to the summits of the highest peaks, which reach elevations of from 11,000 to 14,000 feet and are perpetually snowclad. It is in the valleys between these peaks that are found the many natural lakes, swamps and meadows which furnish sites for storage reservoirs.

The land which will be irrigated from these reservoirs is found almost exclusively in the San Joaquin valley, and is generally of the greatest agricultural value. The water stored in the reservoirs of the high Sierras will have to be passed back into the main rivers down which it will take its course for distances of from 150 to 200 miles before it can be diverted to the valley lands. Between John creek just north of the Stanislaus river and Bear creek, which is south of the Merced river, there are in all about 875,000 acres of excellent irrigable land which must receive its water supply from the Stanislaus, Tuolumne, and Merced rivers.

The Stanislaus ranks among the first of the more important perennial streams which have their origin in the high Sierras. Its catchment area is 970 square miles, and in volume of discharge it ranks third or fourth, being surpassed only by the San Joaquin, Tuolumne and Merced rivers. After proportioning the areas of land in the valley among the various streams according to their convenience for supplying irrigation water, it appears that the Stanislaus river should irrigate 100,000 acres at a duty of 100 acres per second-foot. This would require a perennial discharge of 1,000 second-feet. The discharge of this river from gangings made in 1878 and 1879 varies between 35 second-feet in September and 18,000 second-feet in June. From this it will be seen that its summer discharge should be augmented by storage of the flood waters.

The Tuolumne river is about fourth among the rivers entering the San Joaquin valley in extent of its mountain drainage basin, but is first in perennial discharge. This river should irrigate about 300,000 acres of this region, which at a duty of 100 acres would require a perennial discharge of about 3,000 second-feet. As shown by gaugings, the discharge of this river varies between 60 second-feet in the fall months and 28,000 second-feet, and like the Stanislaus the larger portion of this occurs in the winter and early summer months. The Merced river should irrigate 475,000 acres of the valley region under consideration, which would require a discharge of 4,750 second-feet, while according to the stream gaugings its discharge varies between 50 and 10,700 second-feet. It will thus be seen that water storage is essential on all of these streams in order that they may perform their proper share of the irrigation of the great plain of the San Joaquin valley.

The rainfall over the catchment basins of the reservoir sites surveyed can be only approximately determined. After much careful study of the meagre data at hand it appears that this averages between 35 inches per annum on the catchment basin of the Little Yosemite valley and 47 inches over the catchment basin of Bear valley, while the depth of run-off is estimated to average between 14·4 inches in the case of the former and 18·8 inches in the case of the latter. Further consideration of the subject and a study of the statistical tables of California, compiled by the state engineer, has resulted in the assumption that for the reservoir sites on the Stanislaus the run-off will average 6 acre-feet per square mile of catchment; for those on the Tuolumne 5½ acre-feet, and for those on the Merced 4½ acre-feet per square mile per day.

The following table shows the annual discharge available for storage on each of the reservoir sites surveyed as obtained by an analysis of the results above given and of gaugings made by the surveying parties:

	Catchment area.	Discharge.
	Sq. miles.	*Acre-feet.*
Bear valley	4·7	5,000
Kennedy meadow	67·5	75,000
Kennedy lake	5·4	7,000
Lake Eleanor	48·0	50,000
Tuolumne meadow	169·0	150,000
Lake Tenaiya	11·0	10,000
Little Yosemite valley	132·5	120,000

RESULTS OF SURVEYS.

The relative positions of the various reservoirs surveyed in the high Sierras one to the other, and their exact location by land-office subdivisions, was shown with the preliminary discussion of these surveys in a previous report of the U. S. Geological Survey,[1] as were also photographic views of some of the reservoir sites.

The following table contains the principal data derived from the surveys of the various lake basins:

Site.	Area.	Height of main dam.	Length of main dam.	Length of subsidiary dams.	Capacity.	Cost per acre-foot.	Elevation above sea.
	Acres.	*Feet.*	*Feet.*	*Feet.*	*Acre-feet.*		*Feet.*
Bear valley	348	55	1,660	2 0 230	6,917	$8·27	6,911
Kennedy meadows	128	81	360	....	4,608	16·70	6,182
Kennedy lake	110	31	900	....	2,018	4·65	8,009
Lake Eleanor	1,127	65 89	1,300 1,420	....	45,770 47,290	2·10	4,561 ....
Tuolumne meadows	1,081	75	870	250 515 710	43,185	3·66	8,339
Lake Tenaiya	597	59·5	725	346 360 518 722	23,082	2·49	7,990
Little Yosemite valley	841	115	915	400	45,195	13·67	5,980
Total	4,275	....	....	....	173,575	*7·36	....

---

[1] Eleventh Ann. Rep. U. S. Geol. Survey, pt. 4, 1889–'90, pp. 152–167.

* Average.

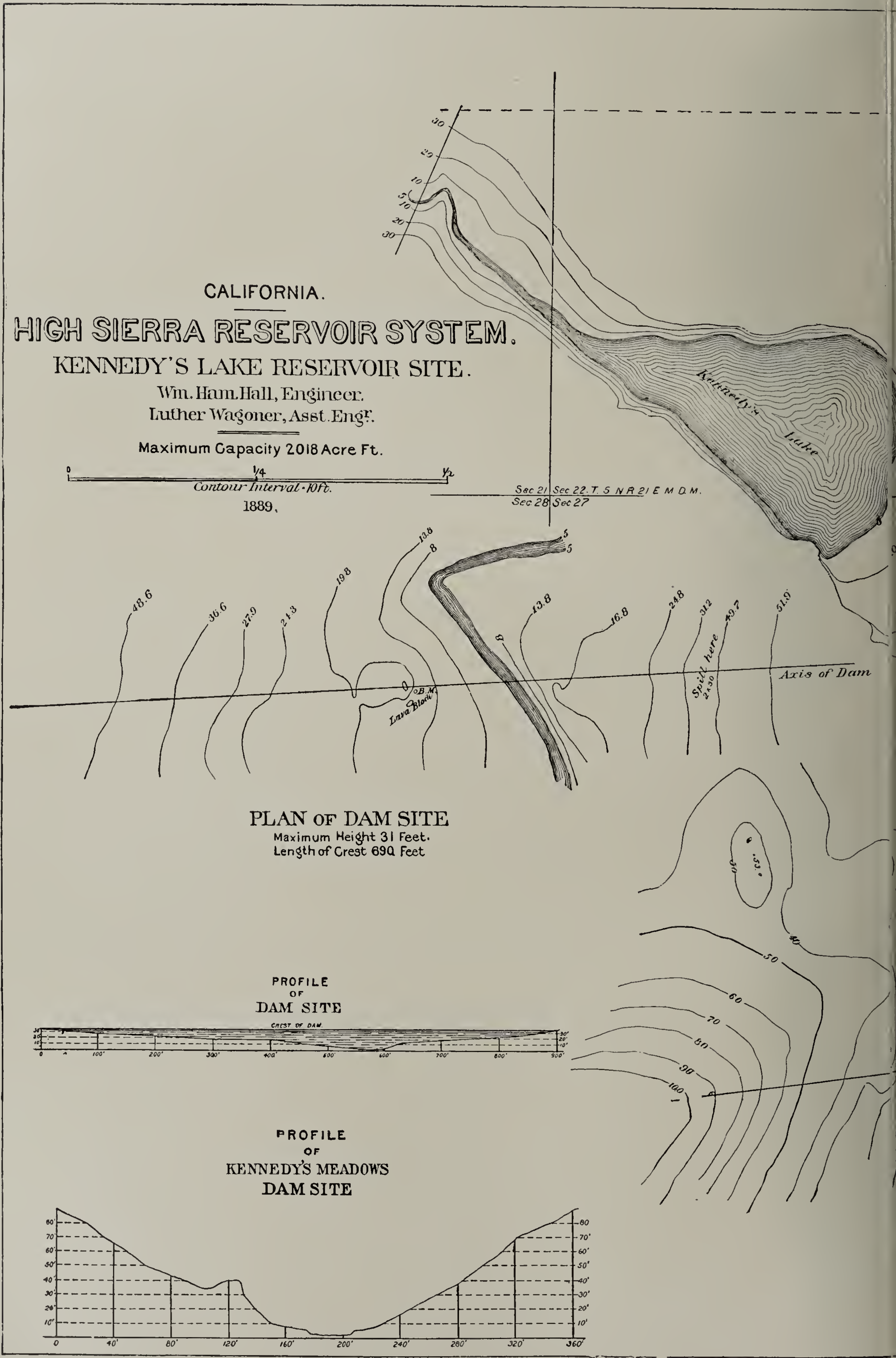
CALIFORNIA.

HIGH SIERRA RESERVOIR SYSTEM.

KENNEDY'S LAKE RESERVOIR SITE.

Wm. Ham. Hall, Engineer.
Luther Wagoner, Asst. Engr.

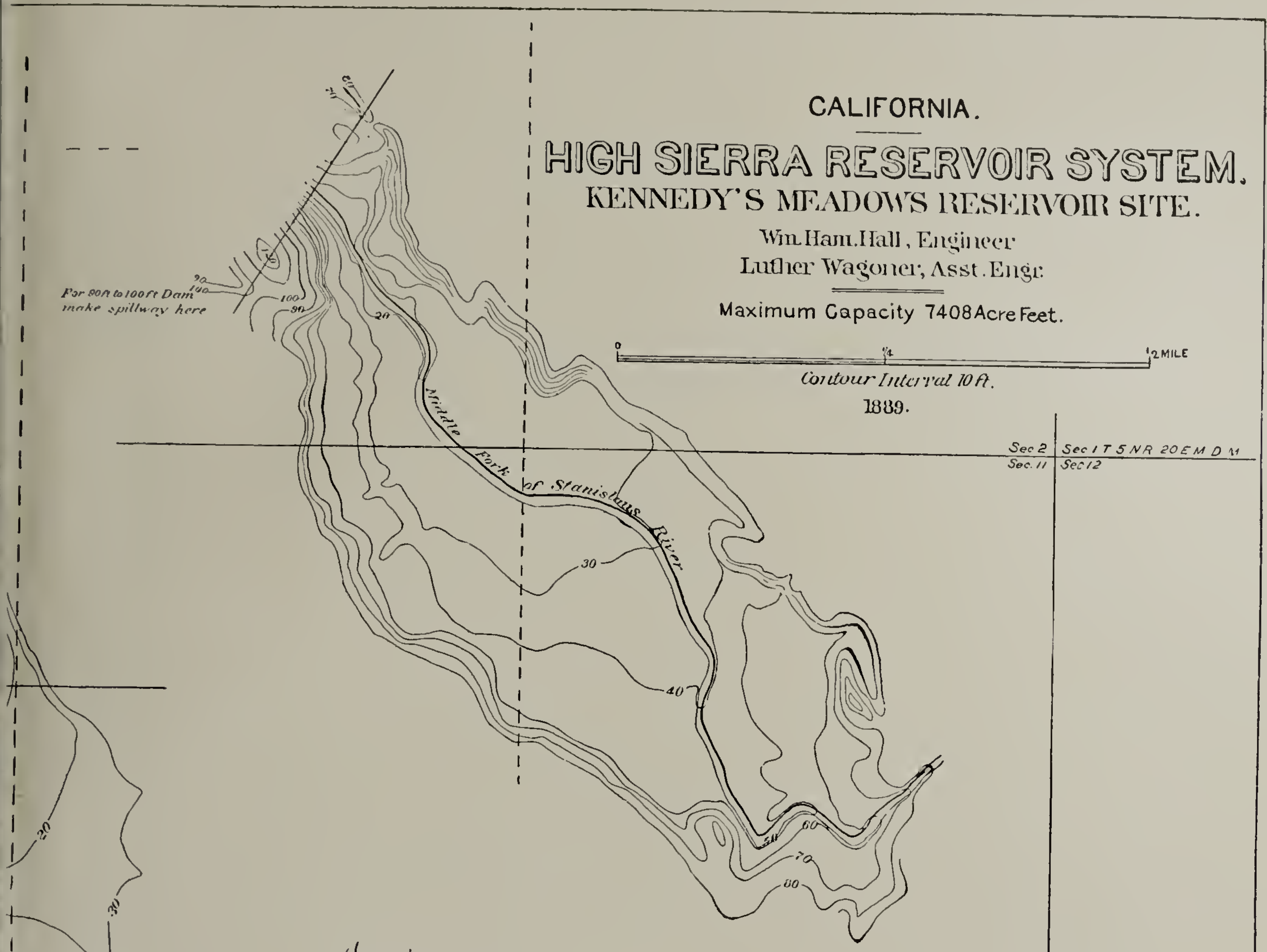
Maximum Capacity 2018 Acre Ft.



PLAN OF DAM SITE
Maximum Height 31 Feet.
Length of Crest 690 Feet

PROFILE
OF
DAM SITE

PROFILE
OF
KENNEDY'S MEADOWS
DAM SITE



CALIFORNIA.

HIGH SIERRA RESERVOIR SYSTEM.

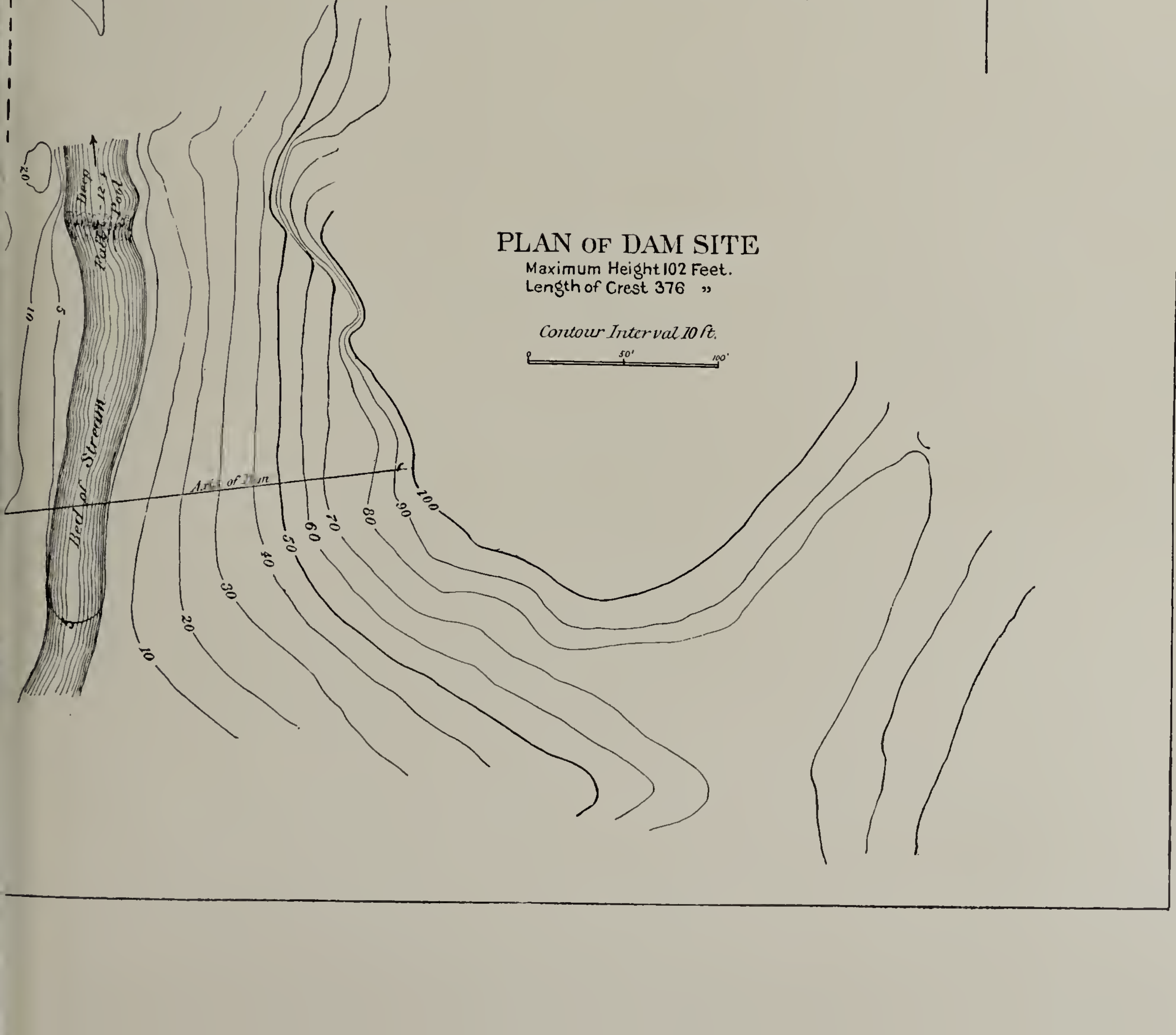
KENNEDY'S MEADOWS RESERVOIR SITE.

Wm. Ham. Hall, Engineer
Luther Wagoner, Asst. Engr.

Maximum Capacity 7408 Acre Feet.

Contour Interval 10 ft.

1889.



PLAN OF DAM SITE

Maximum Height 102 Feet.
Length of Crest 376 "

Contour Interval 10 ft.

The following estimates of quantities and dimensions of the various dams were made by Mr. Luther Wagoner, assistant engineer. The types estimated for were designed and submitted by Mr. Hall, the supervising engineer. The following descriptions of the various types estimated on will give a general idea of their peculiarities.

Type No. 1 is an earthwork embankment; water slope, 1 on 3; back slope, 1 on 2½.

Type No. 2 is an earthwork embankment; water slope, 1 on 2½; back slope, 1 on 2.

Type No. 3 is an earthwork embankment; water slope, 1 on 2; back slope, 1 on 1½.

Type No. 4 is a dry rock dam with wooden face (hydraulic-mining type); water slope, 2 on 1; back slope, 1 on 1.

Type No. 5 is a dry rock dam with wooden facing (hydraulic-mining type); water slope, 3 on 1; back slope, 1 on 1.

Type No. 6 is a gravity-section, masonry-in-cement dam, calculated after the formula of M. Bouvier, as set out by Mr. Gilford L. Molesworth, consulting engineer to the Indian Government, in a note on high masonry dams, printed at Roorkee in 1883.

BEAR VALLEY RESERVOIR.

Bloods station, the site of the reservoir, is 68 miles from Milton, on the Big Tree and Carson valley turnpike. Cement costs $10 per barrel delivered at the dam. The nearest sawmill is 37 miles distant. Tamarack timber is abundant, and sugar and yellow pine may be had within a few miles. Stone is plentiful, but must be quarried.

The proposed work consists of one main dam 1,670 feet long on the crest, with a maximum depth of 55 feet, and of two side dams of the following dimensions: One 300 feet long and 20 feet high, the other 240 feet long and 15 feet high. All of the foundations are clean solid granite (Pl. CLXXVIII).

	Type 2.	Type 3.	Type 5.	Type 6.
Reservoir capacity . . . acre-feet.	6,917	6,917	6,917	6,917
Dam No.—				
1, length . . . feet.	1,670	1,670	1,670	1,670
2, length . . . do. .	300	300	300	300
3, length . . . do. .	240	240	240	240
1, height . . . do. .	55	55	55	55
2, height . . . do. .	20	20	20	20
3, height . . . do. .	15	15	15	15
Material . . . cubic yards.	162,982	114,563	46,323	38,694
Lumber . . . M. B. M. .	. . . . . .	. . . . . .	395,900	. . . . . .
Rate per cubic yard	$0·50	$0·50	$2·00	$10·00
Rate per M., B. M	. . . . . .	. . . . . .	$20·00	. . . . . .
Cost per acre-foot	$11·78	$8·27	$14·51	$55·90
Total cost	$81,491	$57,281	$100,564	$386,940

KENNEDYS MEADOW RESERVOIR.

Kennedys meadow is situated on the upper waters of the Middle fork of the Stanislaus river, and it is 60 miles east of Sonora and 2 miles from Bakers station, on the Mono road. There is a good wagon road from Bakers to the dam site. Yellow pine and tamarack are abundant. Stone can be had from each end of the dam and can be easily quarried. Good loamy soil can be procured by a haul of about 1,200 feet. The 80-foot contour affords a natural spill way (Pl. CLXXV.) The dam site is now inclosed and is used as pasturage.

	80-foot contour.					100-foot contour.	
	Type 2.	Type 3.	Type 4.	Type 5.	Type 6.	Type 5.	Type 6.
Reservoir capacity ..acre-ft..	4608·8	4608·8	4608·8	4608·8	4608·8	7408·7	7408·7
Dam—							
Length.............feet..	360	360	360	360	360	410	410
Height...............do...	81	81	81	81	81	102	102
Material ....cub. yds..	91, 942	72, 870	32, 089	29, 214	12, 800	53, 295	23, 860
Lumber ....M., B. M.	....	....	174, 200	154, 100	....	238, 000	....
Rate per cubic yard..........	$0. 50	$0. 50	$2. 00	$2 ·00	$10 ·00	$2 ·00	$10 ·00
Rate per M., B. M	....	....	$20. 00	$20 ·00	....	$20 ·00	....
Cost per acre-foot.............	$9. 96	$7. 90	$14. 88	$13 ·34	$27 ·80	$15 ·02	$32 ·20
Total cost....................	$45, 971	$36, 435	$68, 662	$61, 510	$128, 000	$111, 350	$238, 600

KENNEDYS LAKE RESERVOIR.

This lake is reached by wagon road, a distance of 58 miles east from Sonoma to Bakers station (on Mono road) and thence 11 miles by a trail over the mountain ridge. Tamarack and yellow pine are abundant. Lumber would have to be whip-sawed. The foundation is detrital, probably a moraine. Earth, loose rock, brush, and bowlders are plentiful. The work consists of one dam 900 feet long on the crest and 31 feet high (Pl. CLXXV.)

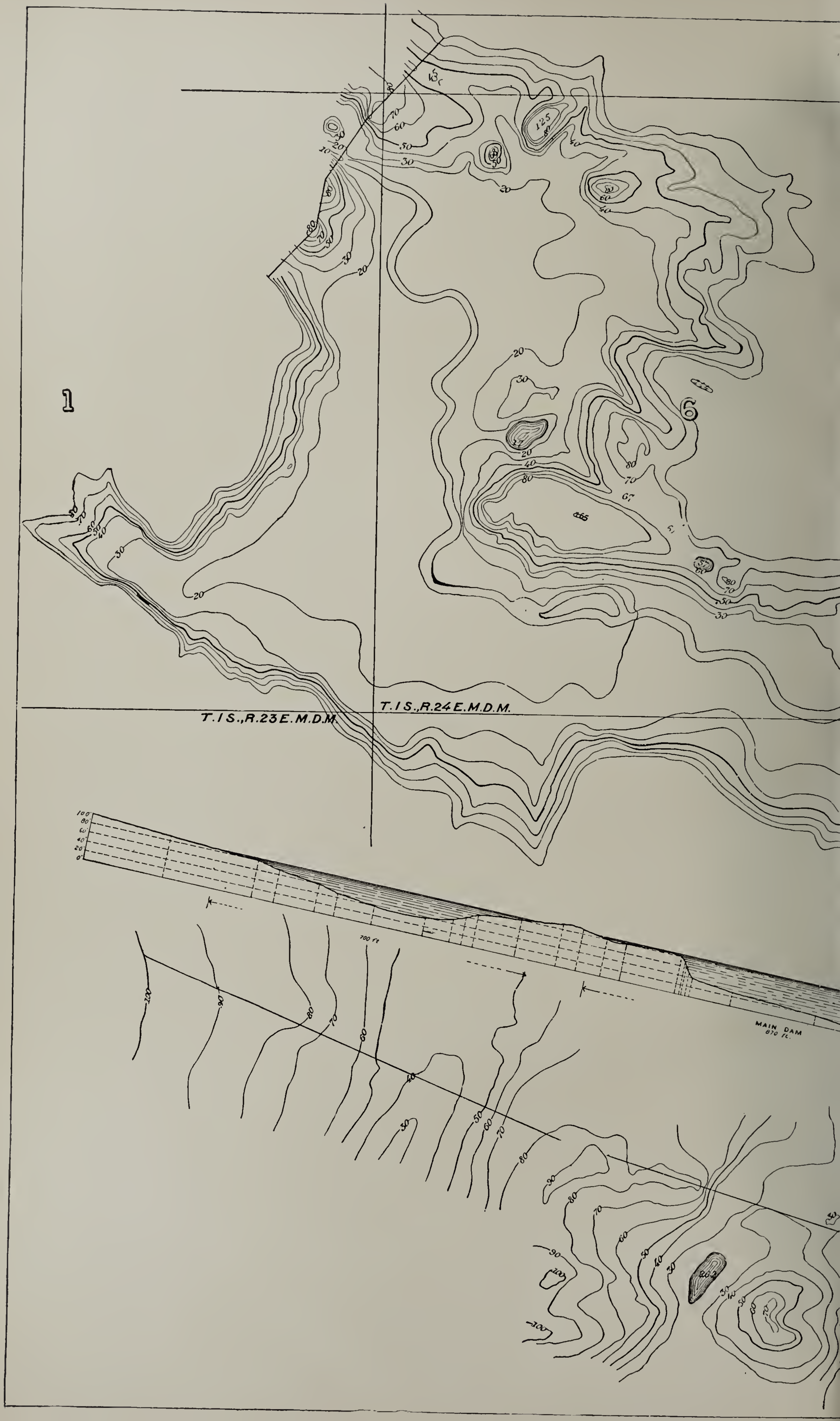
	Type 2.	Type 3.	Type 5.
Reservoir capacity..................acre-feet..	2, 018 ·4	2, 018·4	2, 018·4
Dam:			
Length..................feet..	900	900	900
Height ....do...	31	31	31
Material ....cubic yards..	22, 897	18, 801	7, 819
Rate per cubic yard..................	$0·50	$0·50	$2·00
Cost per acre-foot..................	$5·68	$4·65	$11·72
Total cost	$11, 443·50	$9, 400·50	$23, 638·00

LAKE ELEANOR RESERVOIR.

This is one of the best reservoir sites in the region examined, the watershed being sufficient to fill the proposed reservoir to the height estimated (about 170 feet above low water in the lake). Lake Eleanor is reached by wagon road from Milton to Lord's ranch, via Bradford's sawmill, a distance of 62 miles, and thence by good trail for 15 miles farther. The trail could be changed into a passable wagon road at a trifling cost, thus affording direct communication with Milton by wagon road. The high-water mark of 1862 is still visible and indicates that an ample wasteway must be provided.

At the lower dam site the foundation is all barren granite, but at the upper dam site the foundation is covered in many places with soil and trees to a depth of about 3 feet. By a haul of 1,000 feet from above the upper dam site, a plentiful supply of soil, a sandy loam in character, can be had. Rock, which would have to be quarried in all cases, can be most easily obtained from the level bank of the creek at the upper dam site and from the sides and ends of the dam at the lower site (Pl. CLXXVI).

Estimates have been made for five types of dams to the 150 and 170


1
6
T.1 S., R.23 E. M.D.M.
T.1 S., R.24 E. M.D.M.
125
20
30
40
50
60
70
80
100
80
60
40
20
0
700 ft
MAIN DAM
870 ft.
90
100

CALIFORNIA.

HIGH SIERRA RESERVOIR SYSTEM.

TUOLUMNE MEADOWS RESERVOIR SITE

Wm. Ham. Hall, Engineer
Luther Wagoner. Asst. Engr

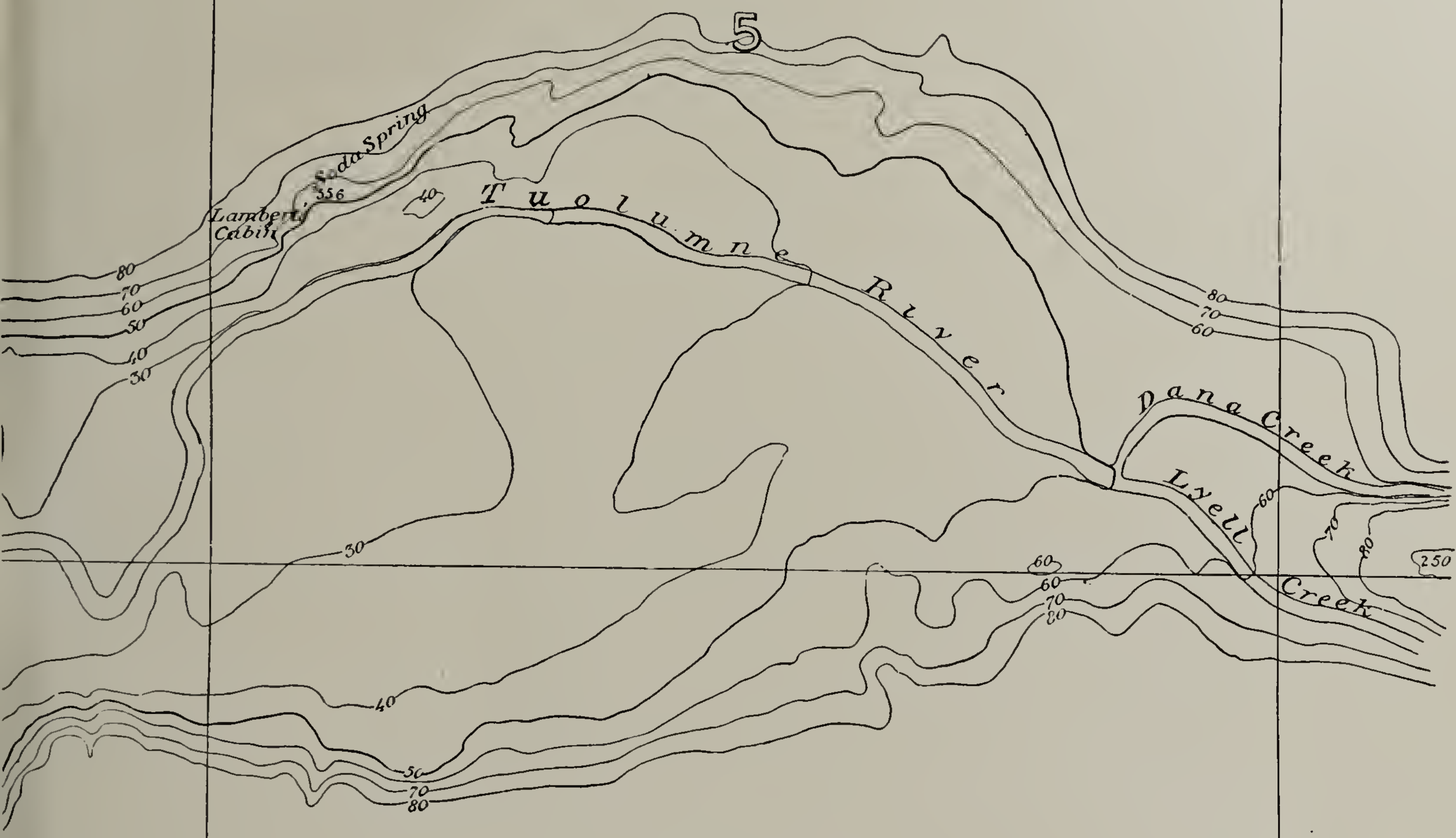
Maximum Capacity 43,185 Acre Feet.

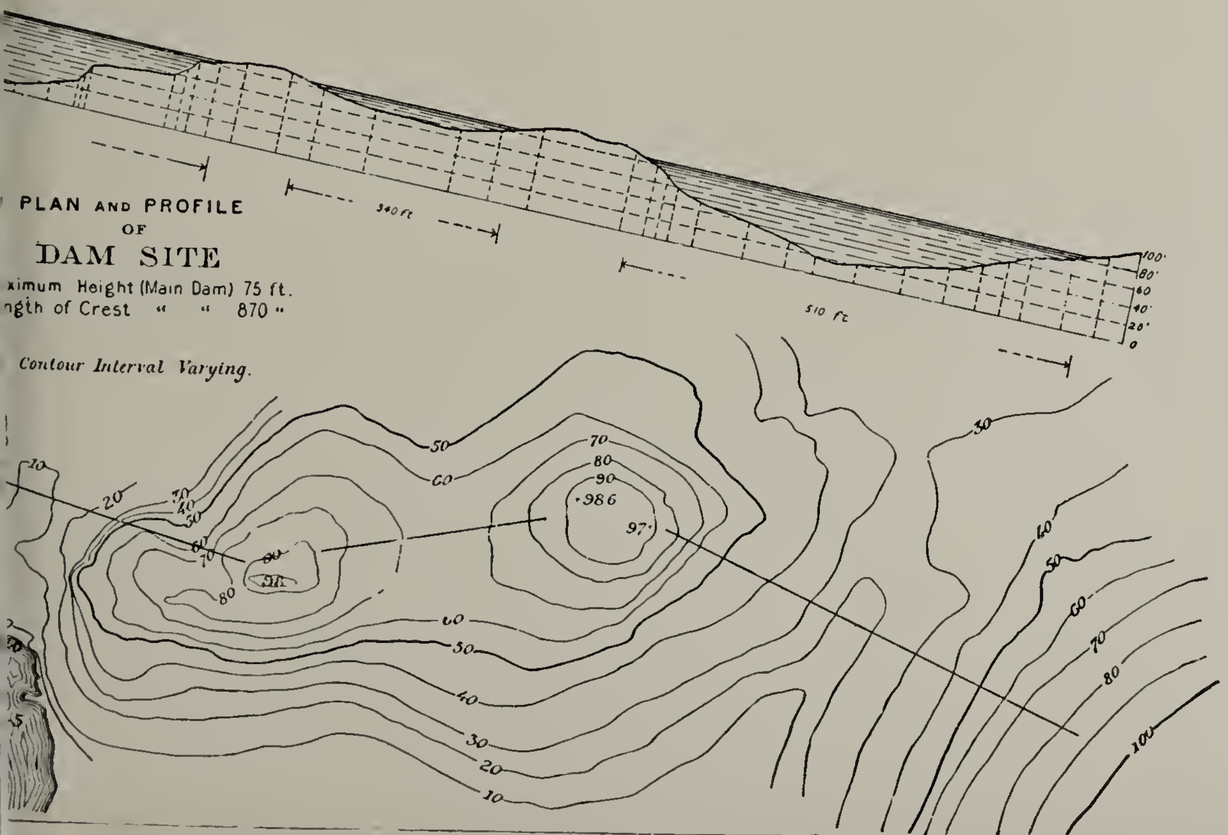
SCALE:

0 ¼ ½ MILE

Contour Interval 10 ft.

1889.





PLAN AND PROFILE
OF
DAM SITE
ximum Height (Main Dam) 75 ft.
ngth of Crest " " 870 "

Contour Interval Varying.

foot contours (low water in the lake is 100 feet) at both the upper and lower dam sites.

UPPER DAM SITE.

	150-foot contour.			170-foot contour.	
	Type 2.	Type 5.	Type 6.	Type 5.	Type 6.
Reservoir capacity .... acre-feet..	45, 769·7	45, 769·7	45, 769·7	68, 786·8	68, 786·8
Dam—					
Length .... feet..	1, 300	1, 300	1, 300	1, 630	1, 630
Height .... do...	65	65	65	85	85
Material .... cubic yards..	186, 505	59, 244	43, 160	129, 574	74, 919
Lumber .... M., B. M..		517, 230		640, 920	
Rate per cubic yard	$0·50	$2·00	$10·00	$2·00	$10·00
Rate per M., B. M		$20·00		$20·00	
Cost per acre-foot	$2·10	$2·81	$9·42	$3·96	$10·88
Total cost	$93, 252·00	$128, 833·00	$431, 600·00	$271, 966·00	$749, 190·00

LOWER DAM SITE.

	150-foot contour.			170-foot contour.	
	Type 2.	Type 5.	Type 6.	Type 5.	Type 6.
Reservoir capacity .... acre-feet..	47, 290·26	47, 290·26	47, 290·26	71, 151·16	71, 151·16
Dam—					
Length .... feet..	1, 420	1, 420	1, 420	1, 610	1, 610
Height .... do...	89	89	89	109	109
Material .... cubic yards..	314, 369	100, 120	60, 367	184, 452	101, 429
Lumber .... M., B. M..		491, 570		746, 928	
Rate per cubic yard	$0·50	$2·00	$10·00	$2·00	$10·00
Rate per M., B. M		$20·00		$20·00	
Cost per acre-foot	$3·32	$4·44	$12·78	$5·40	$14·27
Total cost	$157, 184·00	$210, 071·00	$603, 670·00	$383, 843·00	$1,014,290·00

TUOLUMNE MEADOWS RESERVOIR.

Tuolumne meadows is a valley on the upper Tuolumne river, about 15 miles from its head waters. It is 116 miles from Milton and is reached by the Tioga wagon road, which passes through the valley.

Tamarack is the prevailing wood, with some juniper at higher altitudes. Stone can be had at each end of the main dam by quarrying, also from the sides, but is below the level of the dam. Good loamy soil can be had with an average haul of 1,700 feet.

The main dam is 870 feet long and 75 feet high. There are three lateral dams whose dimensions are, respectively, 250 feet long and 18 feet high, 515 feet long, and 65 feet high, and 710 feet long and 45 feet high. (Pl. CLXXVII). The capacity of the reservoir is 43,185 acre-feet.

	Type 2.	Type 5.
Reservoir capacity .... acre-feet..	43, 185	43, 185
Dam No.—		
1, length .... feet..	870	870
2, length .... do....	250	250
3, length .... do....	515	515
4, length .... do....	710	710
Dam No.—		
1, height .... do....	75	75
2, height .... do....	18	18
3, height .... do....	65	65
4, height .... do....	45	45
Material .... cubic yards..	317, 150	100, 554
Lumber .... M., B. M..		604, 950
Rate per cubic yard	$0·50	$2·00
Rate per M., B. M		$20·00
Cost per acre-foot	$3·66	$4·83
Total cost	$158, 575·00	$213, 207·00

LAKE TENAIYA RESERVOIR.

This lake is situated on the Tioga toll road, distant 110 miles from Milton. The watershed is about 11 square miles. The dam site is nearly all clean granite, with a foot or so of loam in places. Tamarack and yellow pine can be had near by, and stone may be quarried from either end of the dam, while good loamy soil can be had with a haul of 1,000 feet. The main dam is 725 feet long and a lateral dam is 350 feet long and 35 feet high (Pl. CLXXVIII).

	Type 3.	Type 5.
Reservoir capacity ... acre-feet	23, 082·95	23, 082·95
Dam No.—		
1, length ... feet	725	725
2, length ... do	350	350
1, height ... do	59·5	59·5
2, height ... do	35	35
Material ... cubic yards	110, 517	42, 141
Lumber ... M., B. M		317, 200
Rate per cubic yard	$0·50	$2·00
Rate per M., B. M		$20·00
Cost per acre-foot	$2·49	$3·92
Total cost	$55, 258·00	$90, 626·00

LITTLE YOSEMITE RESERVOIR.

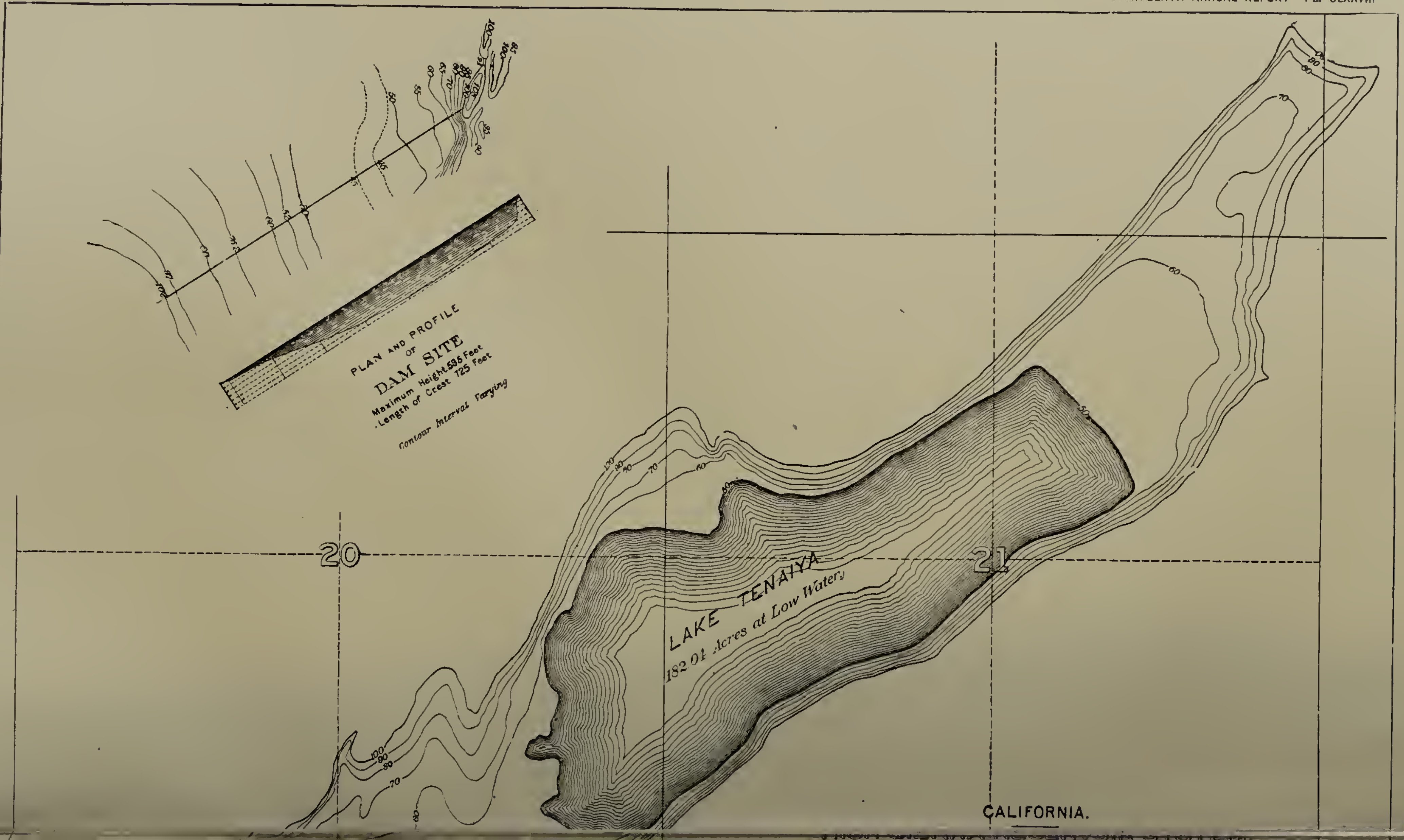
This site is reached by trail 6 miles from Yosemite valley or 8 miles from Glacier point, the latter being the best trail as it avoids a climb of 2,000 feet.

Good timber is abundant and sufficient loose rock can be had with about ⅓ mile haul to construct the main dam. There are two dams required and estimates are given for two contour heights (Pl. CLXXIX).

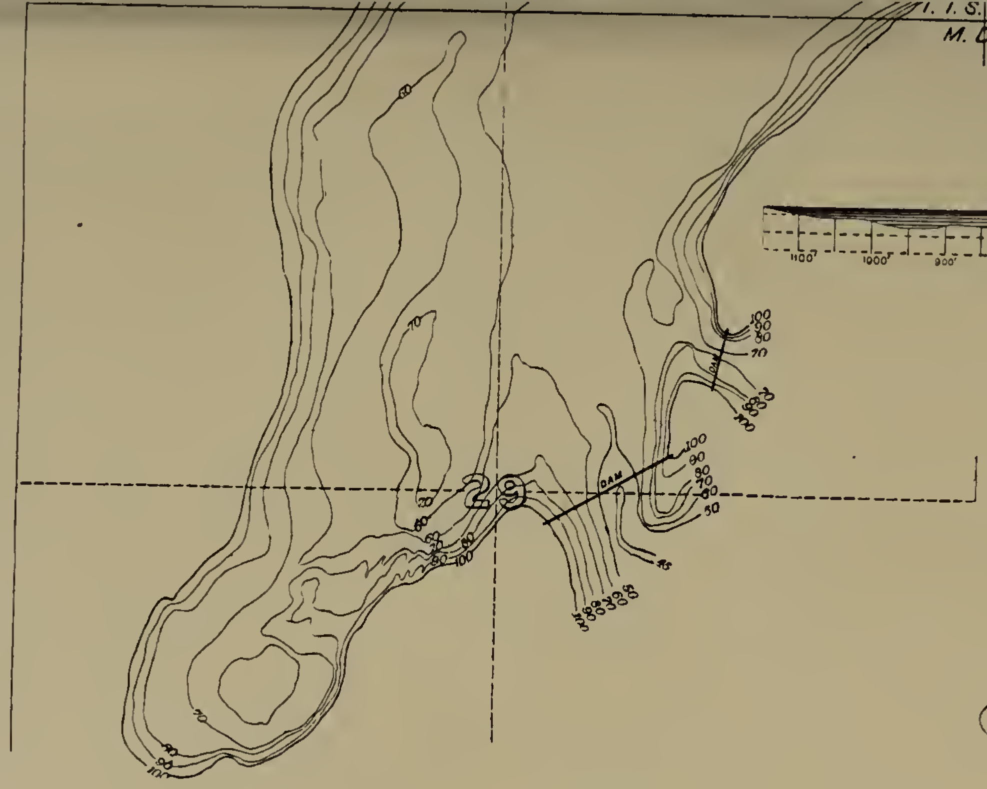
	Type 2.	Type 4.	Type 6.
Reservoir capacity ... acre-feet	45, 195·6	45, 195·6	45, 195·6
Dam:			
Length ... feet	915	915	915
Height ... do	115	115	115
Material ... cubic yards	367, 276	126, 752	61, 821
Lumber ... M., B. M		466, 160	
Rate per cubic yard	$0·50	$2·00	$10·00
Rate per M., B. M		$20·00	
Cost per acre-foot	$4·06	$5·82	$13·65
Total cost	$183, 638·00	$262. 826·00	$618. 210·00

The total area of water surface exposed to evaporation by all these reservoirs is 4,275 acres. The total loss by evaporation from this surface will be about 10,680 acre-feet. The total capacity of the reservoirs being 173,575 acre-feet, the volume of water available for irrigation in the reservoirs will be 162,895 acre-feet.

The average distance to be traveled by the water from these reservoirs, after being turned back into the rivers and before reaching the point of diversion to the irrigable lands of the San Joaquin valley, is, for the reservoirs on the Stanislaus 170 miles, for those on the Tuolumne 190 miles, and for those on the Merced 150 miles. The loss by evaporation and absorption in traveling 170 miles will certainly be very large


PLAN AND PROFILE OF DAM SITE
Maximum Height 595 Feet
Length of Crest 725 Feet
Contour Interval Varying
LAKE TENAIYA
182.01 Acres at Low Water
20
21
50
60
70
80
90
100

CALIFORNIA.



CALIFORNIA

HIGH SIERRA RESERVOIR SYSTEM.

TENAIYA LAKE RESERVOIR SITE

Wm. Ham. Hall. Engineer.
Luther Wagoner, Asst. Engr.

Maximum Capacity 23082 Acre Feet

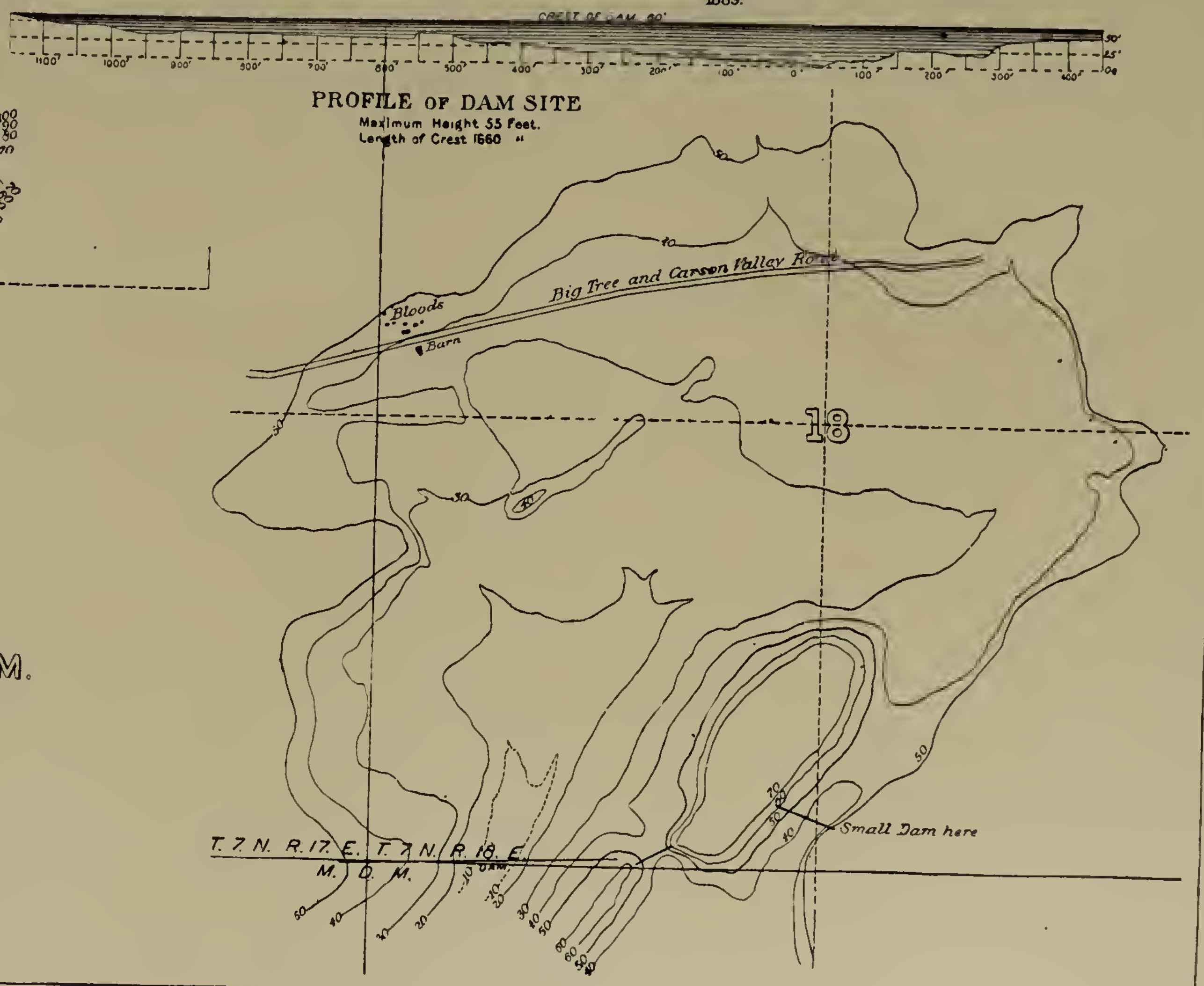
Contour Interval 10 ft
1889

BEAR VALLEY RESERVOIR SITE

Wm. Ham. Hall, Engineer
Luther Wagoner, Asst. Engr.

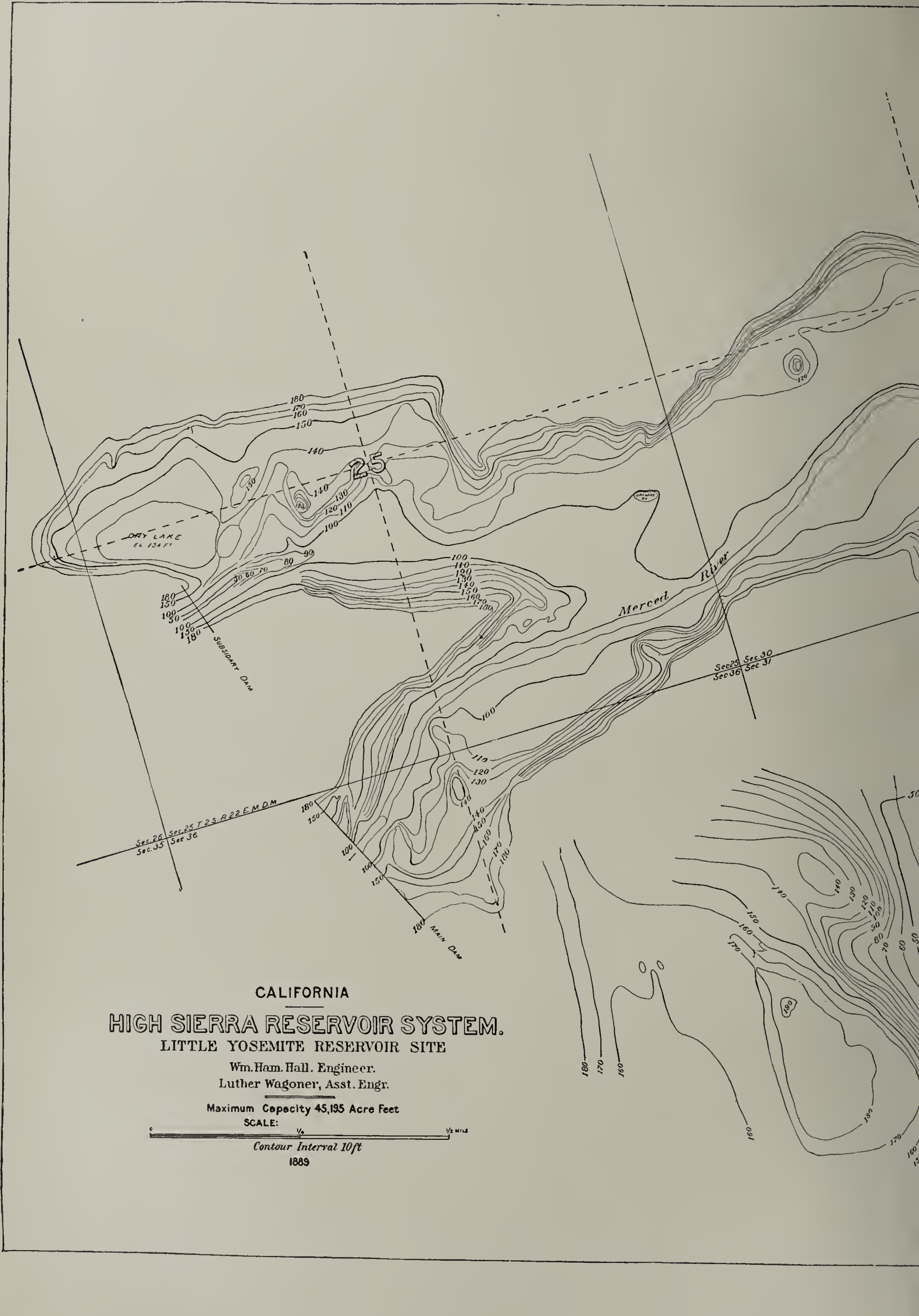
Maximum Capacity 6917 Acre Feet.

Contour Interval 10 ft.
1889.



PROFILE OF DAM SITE

Maximum Height 55 Feet.
Length of Crest 1660 "



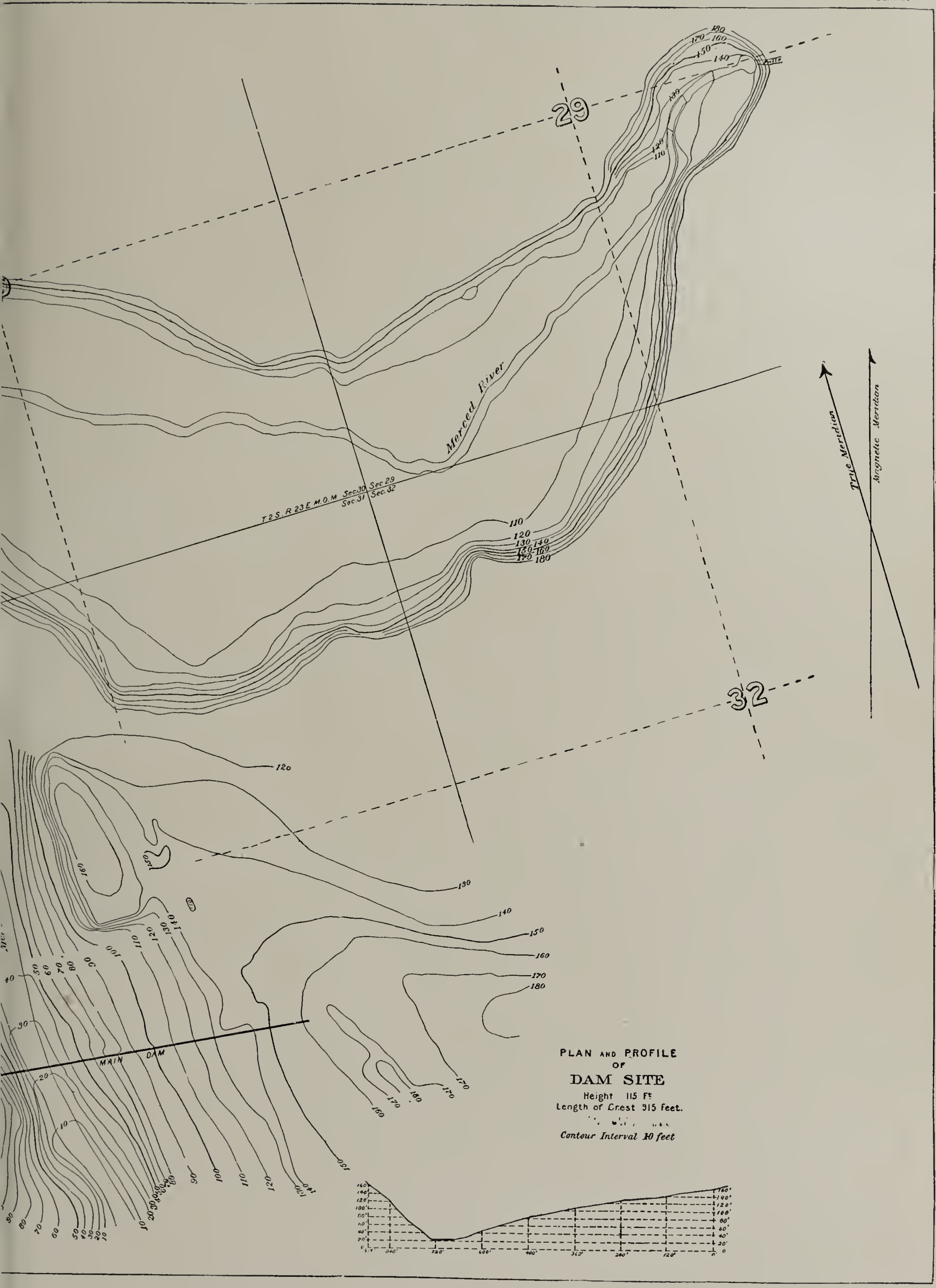
CALIFORNIA

HIGH SIERRA RESERVOIR SYSTEM.

LITTLE YOSEMITE RESERVOIR SITE

Wm. Ham. Hall. Engineer.
Luther Wagoner, Asst. Engr.

Maximum Capacity 45,195 Acre Feet
SCALE:
0 1/4 1/2 MILE
Contour Interval 10ft
1889



PLAN AND PROFILE
OF
DAM SITE
Height 115 Ft
Length of Crest 915 feet.
[illegible]
Contour Interval 10 feet

and not less than 35 per cent as an extreme minimum. It is more likely that it will reach as high as 50 per cent. Assuming the extremely low estimate of 33⅓ per cent as the total loss of the water stored before it reaches the irrigable lands, there will remain only 108,600 acre-feet of water available for purposes of irrigation at the point of application.

As the country is now irrigated, and on the assumption that the duty will shortly reach 100 acres per second-foot, the water supply in this region appears to be short even when allowance is made for the irrigation of but one-half of the dry plains during any one irrigating period of three months, and allowing nothing for foothill and high bench land irrigation. The total quantity of water available for irrigation on the plains derived from the storage systems surveyed is 108,600 acre-feet. At a duty of 60 acres per second-foot this quantity of water will, during a cropping season of four months, irrigate about 27,000 acres.

The final average cost per acre-foot stored by the above projects, based on the quantity of water available, will be $11.78 exclusive of all the minor items of cost, such as regulating gates, wasteways, and other details of construction of works which were not considered in the rough estimate submitted.

CLEAR LAKE SURVEY.

The object of this survey was to make a study of the utilization of the basin of Clear lake as a reservoir, of the conservation of the waters of its drainage basin which are now annually wasted, and the regulation of the supply in its outlet stream for irrigating purposes, and also for the mitigation of winter floods. The special work performed was essentially of a hydrographic and physiographic nature.

Clear lake is situated in Lake county, California, in the Coast range about 75 miles north of San Francisco. The climate and soil of this region are most favorable to the cultivation of semitropic and temperate-zone fruits. Various surveys made in connection with the study of this project were under the immediate charge of Mr. C. R. Rockwood, assistant engineer, and the general arrangement of the parties and the conduct of the work, as well as the location of the lands to be flooded and reclaimed, were fully described in a previous report.[1]

It was well known that the existing property interests along the margin of the lake which would be affected by raising its waters above their normal level were so great that a project involving it would, for financial reasons, be difficult to accomplish, and hence not desirable to adopt. Furthermore, it was recognized that there are physical reasons for not attempting the use of the lake space as a reservoir above the natural water plane; as for instance, the question of sufficiency of water supply. It was hoped, however, that the output of the basin could be controlled and regulated so that the flood waters would never again rise as high as they have risen in the past; so that the mean flood plane and the mean low-water plane should be held lower than they have naturally been; and yet, so that the water to the depth of several feet might be held during winter and spring, to be drawn off from the surface of the lake during the summer months.

---

[1] Eleventh Ann. Rep. U. S. Geol. Survey, pt. 2, 1889–'90, p. 150.

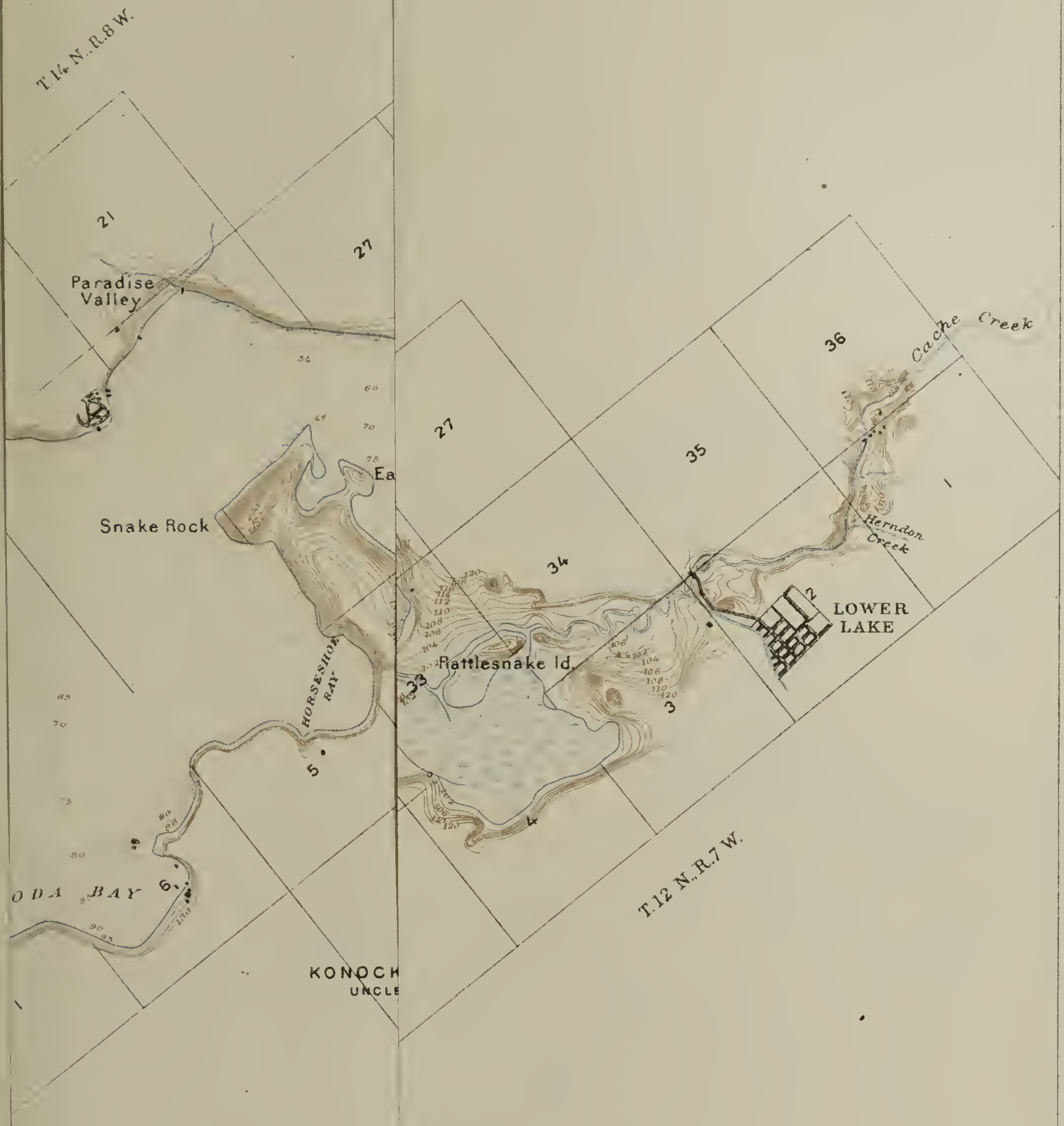
The proposed examination consisted, first, of a detailed engineering study of the existing outlet of the lake; second, of a topographic survey of the lake shore and the immediately adjacent lowlands; and, third, of a hydrographic survey of the lake itself, and particularly of its shallow parts; all of which were supplemented by sustained observations of water-supply output, evaporation, precipitation, etc.

The detailed examination of the outlet was to collect data for locating and estimating the cost of the proposed new or enlarged outlet channel and the regulating structure to be placed therein. The topographic survey was to delineate the outlines of the lake and its various levels, and the location, area, classification, and condition of the bordering lands which might be directly affected, favorably or otherwise, by a lowering of the normal water plane. The hydrographic survey was designed to collect data for projecting probable shore lines of the lake at lower stages of water surface, thus furnishing the means of estimating the volume of its waters and the area of its surface at such lower planes, and so, the differences of such volumes and areas as expressive of the storage space available, and of the evaporative surface that would be successively exposed by lowering it, and the areas of the flats that would be exposed by such lowering.

In making the above studies all available data were gathered relative to the past outflow of the lake at different seasons in different years. Copies of such records as existed of the rise and fall of its surface in different seasons and at different times were obtained and an attempt was made to learn all that was known of a definite and trustworthy nature relative to the hydraulic history of the lake.

As a basis for the topographic and hydrographic surveys of the lake and its shores, a triangulation was projected embracing the entire surface of the lake and depending on a well-chosen base line of several miles in length measured with accuracy over nearly level ground. From this triangulation the secondary stations and signal points for plane-table topographic work were cut in, and from these latter sounding signals were established wherever necessary along the shore by which to guide the hydrographic work.

The topographic work was done in a most accurate manner by the plane table and level. The finished map, Pl. CLXXX, shows the topography of the lake shore in considerable detail from the margin of the lake to a contour about 20 feet above it. This map was made on a scale of 1 mile to the inch and with contours 2 feet apart vertically, while the topography at the bottom of the lake is shown in dotted lines for every 5 feet of vertical interval below the ordinary mean low-water surface. This map also shows the various sloughs, marshes, meadows, and cultivated lands, either reclaimed or capable of reclamation. In making



LIFORNIA

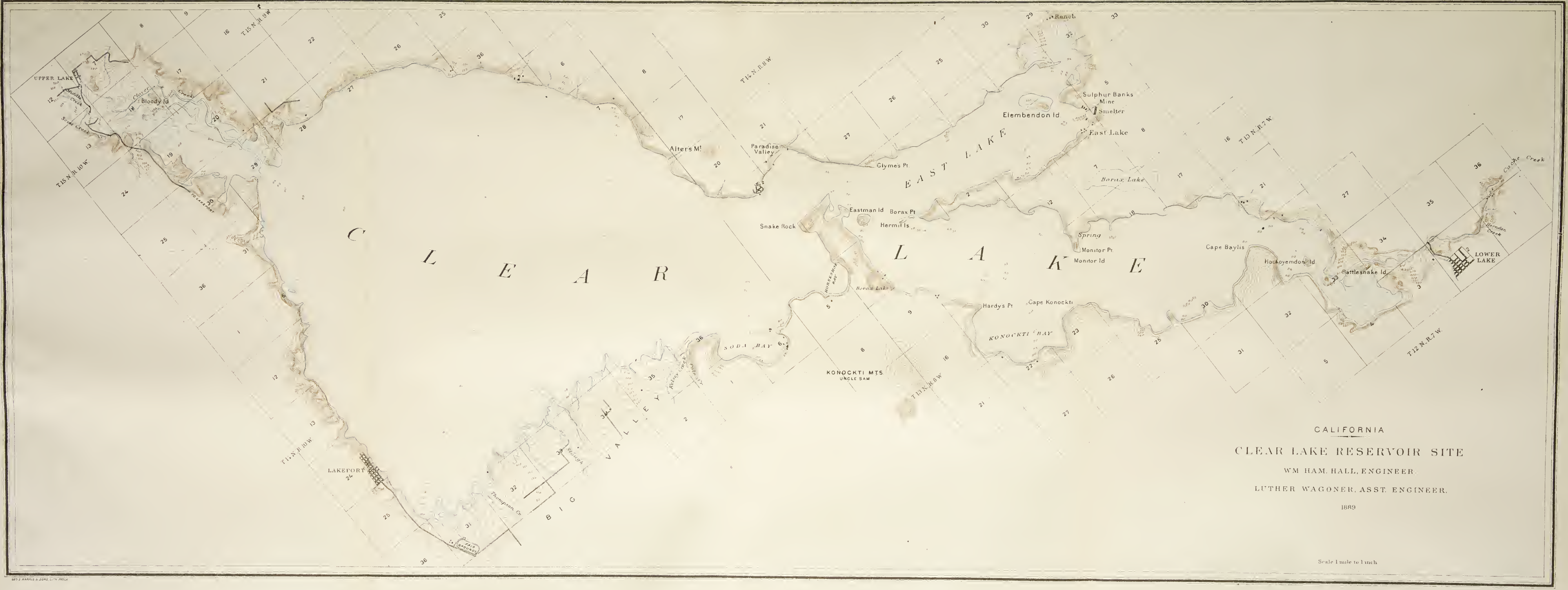
RESERVOIR SITE

HALL, ENGINEER.

ONER, ASST. ENGINEER.

1889

ale 1 mile to 1 inch



CALIFORNIA

CLEAR LAKE RESERVOIR SITE

WM. HAM. HALL, ENGINEER.

LUTHER WAGONER, ASST. ENGINEER.

1889

Scale 1 mile to 1 inch

GEO. S. HARRIS & SONS LITH. PHILA.

the hydrographic survey, over 100 miles of traverse lines were run, while 234 miles of soundings were made. A copy was secured of a record of the rise and fall of the waters of Clear lake kept from 1873 to 1888, inclusive, under the direction of Capt. S. Floyd, of Kono Tayee point, and the levels of the survey were connected with the zero plane of this gauge. Several rainfall records were also obtained, the Kono Tayee observations being especially complete and valuable.

The survey of the outlet of the lake was made in a most accurate manner by transit, chain, and level. This survey extended over a distance of 22,000 feet, covering the region of shoal water at the lower end of the lake, the adjacent marshes, and that portion of Cache creek extending to a point where its bottom is 20 feet below the bottom of the low-water plane of the lake. The result of this survey shows that the area of the surface of the lake at an elevation of 10 feet below mean low water is 56·85 square miles. At mean low water or the assumed 100-foot contour its area is 63·784 square miles. The volume of water between these two planes is 385,300 acre-feet and the volume of water contained between the 100-foot contour and contour 110 is 435,300 acre-feet, with an area of 72·08 square miles exposed to evaporation. The probable loss by evaporation from the surface of the lake varies between 1·1 inches in January and 9·65 inches in August, the yearly rate being about 54 inches or 4½ feet. This is equivalent to an evaporation at the 100-foot level of 184,700 acre-feet and from the 110-foot level of 298,400 acre-feet.

From the record of precipitation kept at Kono Tayee it appears that for the period of fifteen years, from 1873 to 1888, inclusive, the monthly precipitation varied between 0·0 inches in July and 4·67 inches in January, while the mean annual precipitation for this period of years amounted to 20·21 inches, though in at least two years it was over 30 inches. A calculation of the probable mean depth of precipitation upon the entire drainage area of the lake for amounts of rainfall gives from 15 to 30 inches. Estimates of the volume of water falling on the lake and its watershed, the percentages of drainage from the area tributary to the lake, and the total volume brought into it, are shown in the following table:

Precipitation at lake.	Water drained off (area 413 square miles).	Falling into lake at mean low plane.	Total supply.
Inches.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
15	68, 140	51, 290	119, 430
20	203, 040	68, 310	271, 350
25	326, 600	85, 470	411, 070
30	483, 300	102, 580	585, 880

From this table and the statement previously made of the amount of evaporation it will be seen that a large volume of water will ordinarily be available for storage and for purposes of irrigation, especially if the area exposed to evaporation can be reduced by lowering the outlet. If the outlet of the lake could be lowered in such a manner that the lake would store its entire intake with its surface at a level not above the 100-foot contour, the maximum evaporation from this surface would be a mean of 184,700 and 168,000 acre-feet, or about 176,350 acre-feet. With a mean annual precipitation of 20 inches the total receipt from the watershed of the lake is about 271,350 acre-feet, thus leaving about 95,000 acre-feet for irrigation. But the amount stored in the lake will never be retained therein through an entire year, as a majority of the intake occurs during the winter and early spring months, and will be used before July, after which the greatest amount of evaporation occurs. As a consequence of this, it is not unlikely that the total amount of water available for irrigation would be as great as 150,000 acre-feet or sufficient to irrigate nearly that many acres of land.

As a result of the detailed survey for an artificial outlet for this lake, an estimate of the number of cubic yards of excavation is presented in the following tables: First, for a channel to carry 7,500 second-feet of water; second, for a channel to carry 5,000 second-feet of water, and the cost of an embankment which will be a necessary adjunct of this work. This is not a complete estimate of the cost of the works which will be necessary, since no provision is made for protecting the banks of the channel nor for the necessary regulating gates and their accessory works; but the cost of these will be relatively small.

To carry 7,500 second-feet.

Section.	Length.	Fall per mile.	Side slopes.	Bottom width.	Depth of water.	Excavation.
	Feet.	*Feet.*		*Feet.*	*Feet.*	*Cu. yds.*
1	5,400	1	2 to 1	300	8	635.505
2	5,800	2	2 to 1	200	8	653.147
3	3,300	5	2 to 1	120	9	225,748
4	5,100	8	2 to 1	70	10	325,041
Total	19,600					1,839,441
Cubic yards in Cache creek channel to be deducted						418,993
Total						1,420,448

Dredging, 10 per cent, 142,045 cubic yards, at 25 cents	$35,509
Carts, 10 per cent, 142,045 cubic yards, at 15 cents	21,306
Wheel scrapers, 80 per cent, 1,136,358 cubic yards, at 7½ cents	85,227
Total cost	142,042

To carry 5,000 second-feet.

Section.	Length.	Fall per mile.	Side slopes.	Bottom width.	Depth of water.	Excavation.
	Feet.	*Feet.*		*Feet.*	*Feet.*	*Cu. yds.*
1	5,400	1	2 to 1	215	8	465,295
2	5,800	2	2 to 1	130	8	454,956
3	3,300	5	2 to 1	75	9	....
4	5,100	6	2 to 1	50	10	262,449
Total	19,600					1,340,228
Cubic yards in Cache creek channel to be deducted						418.993
Total						921,288

Dredging, 15 per cent, 138,193 cubic yards, at 25 cents	$34,548
Carts, 15 per cent, 138,193 cubic yards, at 15 cents	20,728
Wheel scrapers, 70 per cent, 644,902 cubic yards, at 7½ cents	48,368
Total cost	103,644

EMBANKMENT.

Length	feet	3,670
Top width	do	12
Inner slope		3 to 1
Outer slope		2 to 1
Elevation of top	feet	111
Filling	cubic yards	40,522
Shrinkage in bank, 10 per cent	do	4,052
Total	do	44,574
44,574 cubic yards, at 25 cents		$11,163
Removing silt from channel, 6,000 cubic yards, at 25 cents		1,500
Total cost		12,663

EL PASO RESERVOIR.

For several years past Maj. Anson Mills, U. S. Army, has been interested in a project for storing the flood water of the Rio Grande near El Paso, Texas, and diverting it to the excellent agricultural lands of which there is an abundance on both sides of the river. The only difficulty in the way of this project is an international one, resulting from the fact that the reservoirs will flood both Mexican and American territory.

In the summer of 1889 surveys were made by Mr. W. W. Follett, engineer of the U. S. Geological Survey, for the Rio Grande reservoir at El Paso, which shows that it is practicable to construct a masonry dam at the "Pass," 65 feet in height above the river bottom, with an adequate waste weir. The lake which would be created by this dam will be 14½ miles in length and 4 miles in maximum width, with a surface of about 26,000 acres and an average depth of 23.6 feet. Its contents will be 537,000 acre-feet. (Pl. CLXXXI.)

Two sites for a dam, about 1¾ miles apart, were examined, and the upper one, giving a considerably shorter length of dam, was chosen for survey and estimate. Some difficulties, not of an insurmountable nature, were peculiar to both sites. The river bed in both localities is occupied by quicksands, but it is from 30 to 50 feet in depth at the upper and narrower site and only 22 feet in depth at the lower site. At the lower site one end of the dam will be in Mexican territory; at the upper site both ends will be in the United States. In both of them two railroads, the Southern Pacific and the Atchison, Topeka and Santa Fe, would require to be relocated. This would involve considerable expense, but at the upper site the relocated grades of the latter road could be made to conform readily to the ruling gradient of that division of the road. At the lower site it could not be made to conform without changing the depot and terminal facilities at El Paso. This would compel the Southern Pacific road to enter Mexican territory, in which case the cost of relocation would be great. The upper site would afford facilities for building the dam higher if it should be called for, while with the lower site this would be far more difficult. Owing to the cost of construction, if that were all to be considered, the lower site would on the whole be preferable, but the railroad complications appear to incline the balance in favor of the upper site. The uncertain element in the construction is the keeping open of the excavation in quicksand. The "Poetch" process of freezing the wet sand by pipes has naturally received careful consideration in this connection.

PLATE CLXXXI.

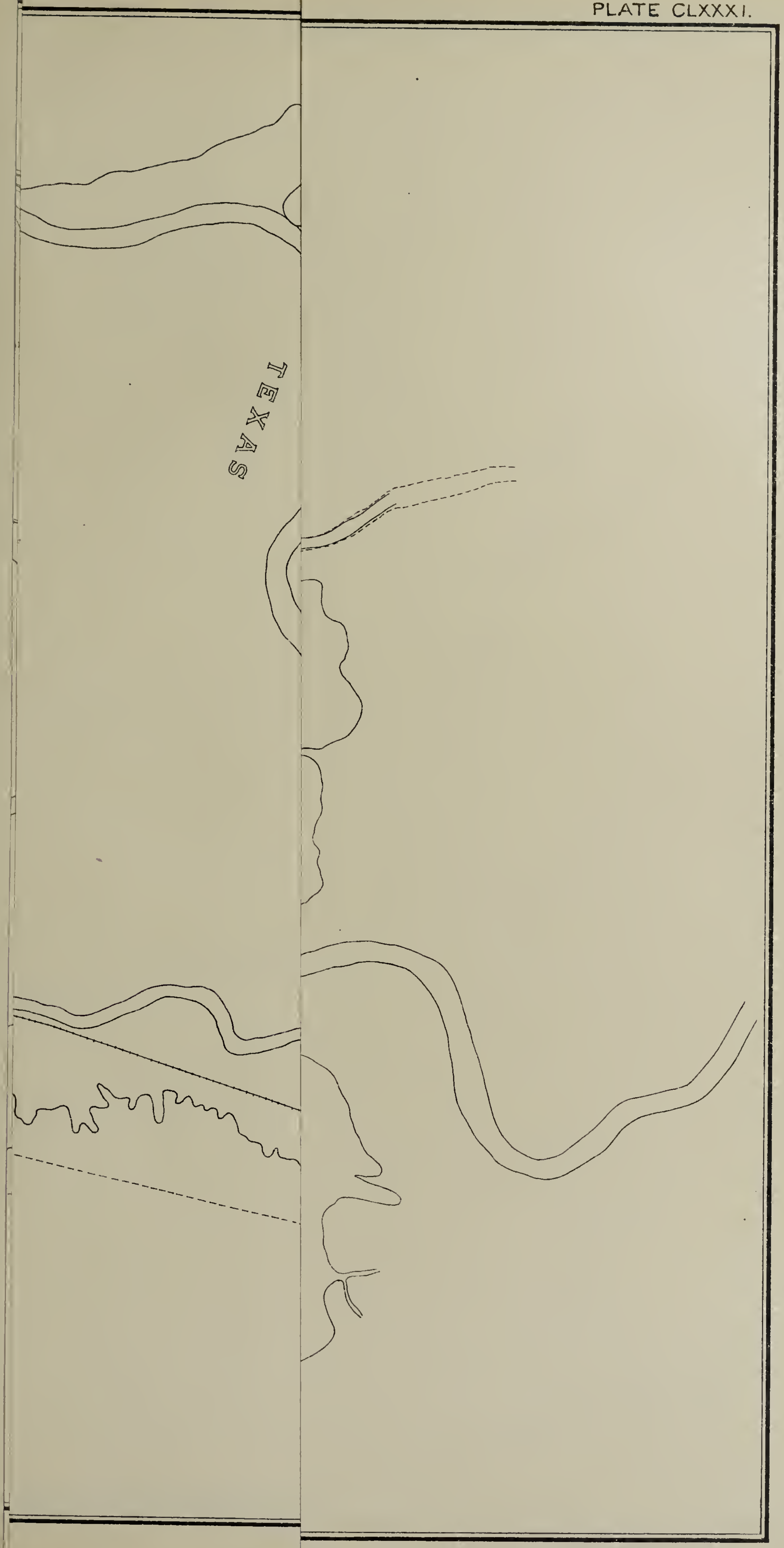
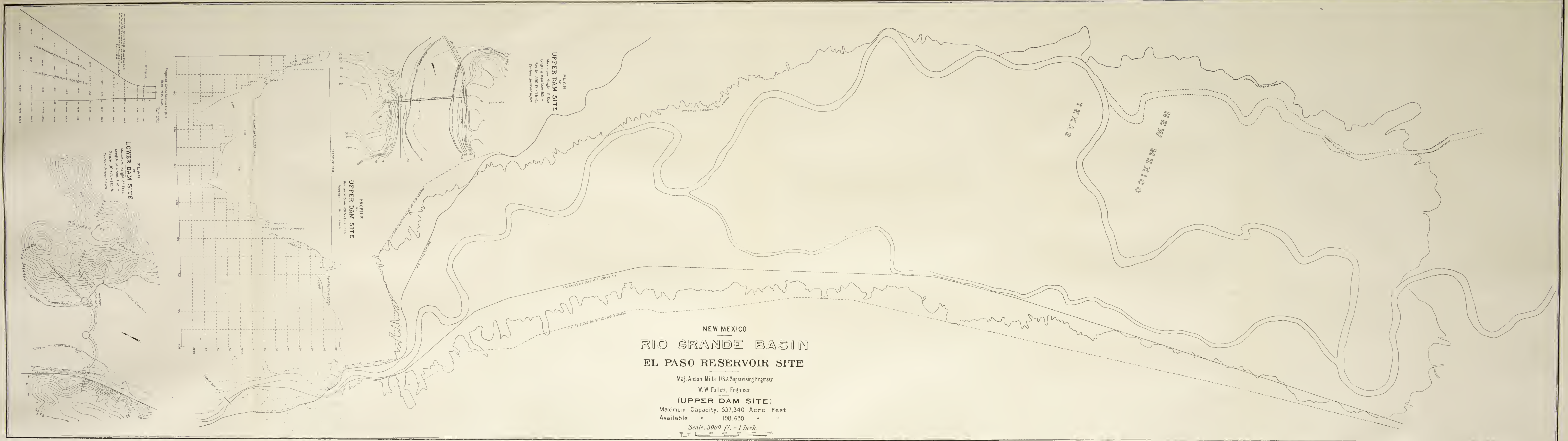


Photo Lith by A HOEN & CO Balto., Md

PLATE CLXXXI



NEW MEXICO

RIO GRANDE BASIN

EL PASO RESERVOIR SITE

Maj. Anson Mills: U.S.A. Supervising Engineer.
W. W Follett, Engineer.

(UPPER DAM SITE)
Maximum Capacity, 537,340 Acre Feet
Available " 198,630 " "

Scale, 3000 ft. = 1 Inch.

A grave question of importance in connection with these reservoirs is the amount of sediment which the Rio Grande carries in suspension. Like all spasmodic rivers in dry climates the amount of this in time of flood is very great. Some investigations have been made on this point with a view to ascertain how long it would require the river to deposit sediment enough in the reservoir to seriously impair its utility. This sediment during the last high-water stage was frequently sampled, and was found to range from about one-fourth to one-half of one per cent of the volume of flow, the average of 118 samples being ·345 of one per cent. This represents only the suspended sediments, and does not include the coarser material swept along the bottom, the quantity of which has not yet been estimated. On the whole, it seems probable that at least one hundred and fifty years must elapse before the reservoir would be seriously impaired by the sediments deposited; and even this period might be prolonged by the use of settling reservoirs along the course of the river through the Jornado del Muerto. There are several large basins in that portion of the river which could be used for that purpose, a new settling basin being constructed whenever an older one is filled up.

From observations conducted during the years 1889–'90 the following tables were prepared, giving the amount of evaporation and the discharge of the Rio Grande at the reservoir site:

Evaporation, 1889–'90.

January	2·0	August	11·4
February	2·0	September	9·2
March	7·0	October	6·8
April	7·3	November	4·6
May	10·8	December	2·9
June	11·2		
July	9·6	Annual	84·1

Discharge, 1890.

Area	square miles	30,000	Annual	acre-feet	1,095,000
April to August	acre-feet	844,920	Run-off	depth, inches	0·6

As the year 1890 was one of average discharge in all the western rivers the above may be taken as a fair average discharge at El Paso. From observations of precipitation continued through a period of twenty-five years the average precipitation on the agricultural lands below the reservoir site during the growing season, from April to August inclusive, is 4·64 inches, and the average annual precipitation is 9·34 inches.

The land that would be brought under a high-line canal from the El Paso reservoir, with a fall of 12 inches to the mile for 60 miles below, would be over 100,000 acres, consisting of about 20,000 above the flood waters of the river and below the waters of the highest ditches now in operation, which would hardly be considered as being redeemed by the project. About 40,000 acres are below the highest flood waters of the river and about 40,000 more are above the waters of the highest ditches in operation, yet these would be below the high-line ditch from the lake, so that 80,000 acres would be redeemed and could justly be taxed for water rights. On the Mexican side there would be perhaps 125,000 acres to be brought under their high-line ditch. This estimate is approximate only, no surveys for it having been made.

The water power made available by the construction of this dam would be of great magnitude. If, as before assumed, the mean annual flow of the river is 1,200 second-feet and one-half that quantity can be utilized in a fall of 50 feet over the dam or from the high line canals below to the lowlands for irrigation, there would be 600 second-feet available for water power, equivalent to 10,143 horse power, less loss by friction, for eight hours every day in the year.

SURVEYS.

The two sites studied are about 1½ miles apart, measured along the axis of the valley, and the lower one is about 1¾ miles above El Paso. The configuration of the valley walls is such that a cursory examination of them would lead one to assume that the upper site is the better, as the valley is there only about two-thirds as wide as at the lower site, and has strong limestone cliffs for walls. But the soundings show that the distance below the surface of the water to hard bottom is twice as great at the upper site as at the lower one. Before this fact was known, however, Mr. W. W. Follett had nearly completed surveys for an estimate of cost based on placing the dam at the upper location. It is for this reason that his estimate is based on that location, and not because it is necessarily the cheaper of the two or the more eligible. It may be that more extended surveys, made with greater care, will result in the adoption of the lower site.

The surveys and estimates were made on the assumption that a dam is to be built with a crest 65 feet above the level of the water in the river at the upper dam site, when the river is carrying about 1,000 second-feet of water, this being considerably below the mean spring and early summer flow.

	Feet.
The assumed elevation of the crest of the wasteway is	3,773·5
Crest of dam	3,778·0
Bottom of dam, on which estimate is based	3,664·0
Elevation on edge of lake and of flow line shown on map	3,775·5

The soundings for bed rock were made in the following manner: The rods were of octagonal cast-steel, pointed as a square pyramid, one for shallow soundings of one-half inch steel 18 feet long, another three-fourths inch and 32 feet long for medium soundings and still another double rod, jointed in two sections of 1-inch diameter, 26 feet long each, for deeper soundings. A tripod 20 feet high with a ring in its apex was necessary to keep these flexible rods in a perpendicular position while they were worked by four men with two iron clamp bars, arranged to adjust to any part of the rod as it passed down. The entire 3 miles of the pass were prospected for bed rock at all points where the walls of the canyon rendered it practicable to build a dam; but only two available sites were found, the 52-foot rod failing to touch bottom at other points. It is not absolutely certain that the true bed rock exists as described in the soundings or, if it does exist, that it is free from faults or rifts, or of such a quality as to support a dam of the kind designed, but every evidence possible with such soundings was obtained, being the more positive at the lower site by reason of the rock being so much nearer the surface and the friction on the rods consequently much less.

Working from the elevations previously given it is found that a lake will be formed (Pl. CLXXXI) whose extreme length when water is running over the wasteway 2 feet deep will be 14½ miles above the upper site; its extreme width near its upper end will be nearly 4 miles and it will cover over 26,000 acres, having an average depth of 23·6 feet. Its extreme depth, about 65 feet, will be in the channel just above the dam. With the water just level with the crest of the wasteway, the area covered will be 24,900 acres, the average depth 21·6 feet and the total cubic contents 537,340 acre-feet, of which 198,600 cubic feet will be contained in the upper 10 feet of the lake. This last amount is available for irrigating purposes and will irrigate that number of acres. The capacity of the reservoir below contour 3,763·5 feet was found to be 338,712 acre-feet; between contours 3,763·5 and 3,773·5 feet the contents of the reservoir will amount to 198,630 acre-feet. These quantities are so vast that one fails to grasp their meaning without some study; but such comprehension will be assisted by comparison of it with the two largest reservoir schemes now on foot in the United States, as follows:

The San Mateo dam, about 20 miles from San Francisco, will be 170 feet high above bed rock, about 700 feet long on top, and will impound 98,200 acre-feet, or between one-fifth and one-sixth of the contents of this reservoir. The New Croton dam, as projected to be built across the valley of the Croton river, near Cornells, above the city of New York, will be 248 feet high above bed rock, 2,180 feet long on top, and will impound a reservoir covering 3,900 acres and containing 92,000 acre-feet, about the same as the San Mateo dam.

So here at El Paso, we should by a dam only 114 feet in extreme height and 590 feet long on top, impound between five and six times as much water as either of the dams mentioned, and would have available for what are called "high-line canals" over twice as much water as their total contents.

FLOOD WATER STORAGE.

It is intended to use the upper 10 feet of the reservoir both for the storage of irrigation and flood water. As the irrigation season begins in February and the flood flow of the river comes in April or May, these two purposes are not conflicting. The effort must be to enter April with the water at a rather low stage—say 8 feet below the crest of the wasteway. Thus over 22,000 acres of reservoir surface will give a storage of 176,000 acre-feet. The river, when flowing 6,000 second-feet, will carry 11,900 acre-feet per day. Half this amount can be allowed to pass the dam, going down the channel and the ditches. The other half is what must be stored and 8 feet will hold thirty days of this flow, which is a longer continued flood of 6,000 second-feet than there is any record of. So the reservoir will fulfill satisfactorily the primary object of its construction, viz., storing flood waters, and so prevent eroding floods in the river below El Paso.

The areas of irrigable land below, and which may be served by this reservoir, are as follows:

In Texas 15,200 acres of patented land in "El Canutille" grant and 1,630 acres surveyed but not patented. This patented land is almost all swamp land. Not over 60 acres are cultivated, though about 100 acres have been recently under cultivation. About one-fourth of it is moderately well timbered, mostly with cottonwood. The other three-fourths is composed of tornillo thickets and sandbars, some naked and others overgrown with willows, and of flat lands which overflow every time the river rises.

A fair estimate of the value of the property in Texas which would be destroyed by filling the reservoir is as follows:

3,800 acres of timber land, at $5	$19,000
5,700 acres of land not overflowed, at $2	11,400
5,700 acres of sand bars and overflowed lands, at $1	5,700
1 limekiln	1,000
5 adobe houses, at $300	1,500
7 pole houses, at $100	700
Total for Texas lands	39,300

All lands to be submerged on the west bank of the Rio Grande in New Mexico form a part of two large Spanish grants, neither of which is patented. These two grants are the Francisco Gracia grant and the Refugio Colony grant. The former is at the lower end of the lake and has no improvements whatever upon it, except a little fencing. It was surveyed in 1883, its eastern boundary, as then located, being the river channel. As it is not confirmed, and as there are no improvements, some amicable arrangement could probably be made with the claimants to take in lieu of it land equally good elsewhere, making this portion of the site cost nothing. There are 3,120 acres of this. The Refugio Colony grant, which lies above the Garcia grant, was surveyed in 1877. The lake would submerge 6,320 acres, of which about 2,500 acres is cleared and under ditch.

The following is an estimate of the value of this property which will be submerged:

2,000 acres of land cleared and broken, at $3	$6,000
9 miles irrigation ditches, at $1,000	9,000
12 adobe ranch houses, at $400	4,800
20 adobe houses at La Union, at $500	10,000
Total cost of Refugio Colony improvements	29,800
Total cost of Texas lands	39,300
Total cost of site	69,100

UPPER SITE FOR DAM

As before stated, this report is confined to a discussion of the upper site chosen for the dam. Referring to the map, it is seen that the dam, as there located, is placed at the extreme lower end of a pass, the full length of which is about 1,000 feet. The reason of this location is that no hard bottom could be found with a sounding rod 50 feet long in any other part of the pass, except at its lower end. Here it varies from 8 feet to 50 feet below mean water in the river. The bottom found is probably a soft limestone. The rod would not ring when churned on it, but could not be churned or driven into it.

Examination of the cross section of the valley shows that the soundings indicate a channel in the rock near each bank, with a hill between them. It may be possible that it will be necessary, in order to obtain solid foundation, to remove this hill, bringing the rock bottom down to the level of the two channels. The fact that a line of soundings, taken 100 feet down stream from the center line, shows the bottom almost level, and at an elevation but little above that of the channels, where they cross this line, would indicate that this might have to be done. While this may happen, it is improbable, hence an estimate of cost has been made based on a footing of the dam being carried down to a depth shown on the map by the stepped line. The walls of this canyon are of limestone, some of which is very hard and solid. It is, however, traversed by layers of small limestone, firmly cemented together. This does not present a very solid appearance on a first examination, but careful study of it indicates that it will be practically impervious to water, even under 60 to 80 feet head. There are also many dry seams running through the limestone, but none of them are continuous. In other words, the rock has no defined planes of cleavage. These seams will not be at all likely to give any trouble.

DESIGN OF DAM.

While a curved dam is for many reasons preferable to a straight one, the configuration of this site is such as to force the designers to propose a straight one. The problem is to get the ends of the dam as far up stream as possible, so as to get the benefit of the bluffs, but at the same time to keep the center as far down stream as possible, so as to set it squarely upon the rock hill, shown by the soundings to exist in the bottom of the river. The only solution of this is a straight dam.

The height of the crest of the dam is datum elevation 3,778, or 4½ feet above the crest of the waste-weir. As with a length of waste-weir of 200 feet, water flowing over it 4½ feet deep would be passing 6,300 second-feet, and the six 48-inch pipes under 53-feet head would be passing 4,840 second-feet more, and as the maximum flow of the river of which we can find a record is 7,200 second-feet, this height is evidently sufficient to insure that no water will flow over the crest of the dam.

The cross section adopted is one derived from the profile recommended by Mr. Alphonse Fteley for adoption at Quaker Bridge, New York, and is "Practical profile No. 2" of Wagmann's "Design and Construction of Masonry Dams." It is computed on the assumption that the specific gravity of the masonry is 2·33, or its weight 143·83 pounds per cubic foot. The materials which will be used in this dam will probably weight a little more than this, but the resultant difference in the required cross section of the dam will be very little.

Through the dam, at a distance of 48½ feet below the crest of the waste-weir, are to be placed six 48-inch iron pipes. These pipes are for passing the water necessary to be sent down stream, when the water is level with or below the crest of the weir. The following is the discharge of water through a 48-inch pipe 35 feet long under varying heads.

	Second-feet.
Under 40-feet head	701 ·0
Under 46-feet head	751 ·7
Under 52-feet head	799 ·2

From this it is seen that the pipes themselves can discarge 4,640 second-feet when the water is just level with the waste-weir, or when the pipes are under a pressure of 48½ feet head. A waste-weir 200 feet long will pass 3,430 second-feet of water, with a depth of 3 feet over the weir crest.

Above the elevation, 3,714 feet, the amount of masonry in the dam will be 629,926 cubic feet; deduct coping 10 feet by 590 feet by 1½, in all 8,850 cubic feet, leaving 621,076 cubic feet or 23,002 cubic yards. Below the elevation, 3,714 feet, the cubic contents of the dam will be 24,761 cubic yards, which is the amount of masonry below the water level.

About one-half to three-fourths of a mile above the upper site, at the top of the cliffs forming the right bank of the river, there is a very good quality of sandstone, in deposits apparently sufficient to furnish enough material for the whole dam. Its transportation would, however, be expensive, and material nearly as good can be found immediately at hand. The limestone ridges, forming the walls of the pass just above the dam site, will furnish good hard stone. It will not work to smooth faces without a great deal of labor, so the kind of masonry should be "Cyclopean rubble," or rubble masonry composed of the largest stones it is possible to quarry and handle.

The foundation of the dam, or all of it which is below 3,714 feet, ought to be put in during one season. This 24,760 cubic yards will be laid at a more rapid rate than that higher up the dam, because no pains need be taken to keep the faces perfectly smooth, so long as they generally conform to the required outline.

The handling of the alluvial deposit in which the foundation must be excavated is a much more difficult problem. Two methods may be employed. One is to make use of the Poetch freezing process to freeze a dam across the river above and another below the space to be excavated, and then pump out the sand with a sand-pump. The other is to sink two lines of cribs filled with stone, one above and another below the space where a foundation is to go. Some still better way may be found. The depth to be overcome is not so great (50 feet at the deepest place) that some way can not be found to overcome it at a reasonable cost. The hill of rock in the bottom of the river can be utilized in construction to divide the work in two parts and let the river run on one side while the other side is being put in. A coping of sandstone 18 inches thick should be put on top of the dam, well clamped together and dowelled to the masonry beneath, so that wave action will not rupture the crest.

ESTIMATED COST.

The one uncertain item in the cost of this work is that of making and keeping open the excavation in the river bed while preparing the foundation and laying the masonry up to the water line. If no material came in from behind, whatever cofferdam is used, it would be necessary to move about twice as much alluvial deposit as the contents of the dam below the water, or about 50,000 cubic yards. Whatever system is used, some material is sure to come in. It is safe to say that there would come in half as much as is thrown out, making, say, 75,000 cubic yards in all to be taken out. This can be removed by sand-pumps very cheaply, say for 10 cents per cubic yard. An estimate is made which is intended to be an approximation of the cost of two wooden and stone cofferdams. Each coffer dam would be 360 feet long and would have an average height of 35 feet, and an average thickness of 30 feet. Its sides would be made of solid 12 by 12 inch timber, with bottom and cross walls every 16 feet of same size timber, and there would be 1,442,600 B. M. of timber in both. This timber, which need not be of first quality, can be laid down at the dam site for $18 per thousand B. M. The labor and ironwork required in putting it in place will amount to, say, $10 per thousand B. M., or $28 per thousand B. M. in all. Both dams will contain 20,533 cubic yards of rock. This can be put in very cheaply, as there is any amount of it close at hand. It will probably cost 75 cents per yard to put it in place.

It will be necessary to run a bilge pump during the whole time the masonry is being laid below the water level. If the foundation is put in during one season the pump would have to be run about one hundred and eighty days and one hundred and eighty nights, or an equivalent of three hundred and sixty days. This would cost, for fuel and attendance, $7 per day.

The cost of the masonry both below and above water would be about as follows:

	Cubic yard.
Quarrying rock	$0·75
Transporting (average haul about 600 feet) by cable or trams	·25
Mason work, laying	1·45
Cement, two-fifths barrel, at $4·50	1·80
Cost of plant, engines, etc	·25
Total	4·50

The total cost for constructing the dam will be—

1,442 M. B. M. in lumber in caissons, at $28	$40, 376
20,500 cubic yards of rock in caissons, at 75 cents	15, 375
75,000 cubic yards of sand excavation, at 10 cents	7, 500
2,670 cubic yards of rock excavation under water, at $2	5, 340
360 days' use of steam pump, at $7	2, 520
47,764 cubic yards of rubble masonry, at $4·50	214, 943
8,850 cubic feet coping stone laid, at 50 cents	4, 425
156,000 pounds piping, at 2¾ cents	4, 290
Six 48-inch valves, at $1,400	8, 400
Laying 6 pipes and valves, at $200	1, 200
Total	304, 369

The most difficult engineering problem to solve in connection with this work is the removal from the bed of the lake of the Southern Pacific and Santa Fe railroads. The two cross each other by an over-grade crossing, about 1,000 feet south of the proposed upper dam site. The Southern Pacific runs on up the pass on the right bank of the river a little over a mile, then swinging around a spur of the hills, runs to the westward, and finally climbs up out of the river valley, striking out in a northwesterly direction across the plains. Its ruling gradient both east and west bound is 1 per cent, compensated 0·02 per degree of curvature. Its maximum curve is 10°.

The Santa Fe follows up the left bank of the river for a long distance above El Paso. Its maximum south-bound grade is 0·4 per cent, and north 0·5 per cent, both compensated 0·06 per degree of curvature. Its maximum curve is 7°.

The problem is so to relocate these lines that their maximum grades and curves will not be exceeded, that they will still have an overhead crossing, and that they will be high enough when first coming alongside of the lake to be above its waters.

REMOVAL OF THE SOUTHERN PACIFIC RAILROAD.

As the Santa Fe has so light a ruling gradient it was found to be advisable to change the crossing of the two roads, reversing their positions. To do this and to obtain 21 feet clear headroom at the crossing, it was necessary to lower the Southern Pacific 12 feet at the point chosen for the crossing. This point is about 1,000 feet southeast of the present one and on the south side of a deep gulch.

Referring to the map it is seen that the new line for the Southern Pacific leaves it at point southeast of the smelter. It follows moderately close to the old track up to the crossing of the Santa Fe, where it is laid just as close to the old line as it is possible to have it and give room to grade the new line without disturbing the old. This is done to utilize as far as possible a heavy cut on the present line just south of the proposed crossing. This location can not be bettered. Beyond the crossing the line is preliminary and hastily defined. In many places it can be much improved in location, both as regards the amount of grading and the curvature. The river crossing, while only some 150 feet downstream from the present crossing, is over 300 feet shorter.

The following is an estimate by sections of the amount of subgrade work, taken from the profile, and of required track material. Where cuts are of classified material and the adjacent fills must be made from loose rock borrow, only the excess of the fills over the cuts is estimated.

Section.	Earth excavation.	Loose rock excavation.	Solid rock excavation.	Earth embankment.	Earth barrow.	Pile bridge.	Iron pipes.	
							18-inch.	24-inch.
	Cu. yds.	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*		
1	32,570	....	30,770	....	....	....	....	90
2*	....	10,510	51,810	....	45,000	400	85	42
3	....	....	30,025	....	40,000	....	75	24
4	2,697	....	1,986	24,232	2,000	150	90	58
5	9,963	....	8,000	22,488	....	135	....	....
6	2,360	....	....	11,434	....	15	....	84
Total	47,590	10,510	122,591	58,154	87,000	700	250	298

* Has also 500 feet of Howe truss bridge.

Estimated cost of rebuilding Southern Pacific railroad.

47,590 cubic yards of earth excavation, at 10 cents	$4,759
10,510 cubic yards loose rock excavation, at 30 cents	3,153
122,590 cubic yards solid rock excavation, at 70 cents	85,813
58,150 cubic yards earth embankment, at 10 cents	5,815
87,000 cubic yards of loose rock barrow, at 30 cents	26,100
700 linear feet pile bridge, at $10	7,000
500 linear feet Howe truss bridge, at $65	32,500
350 linear feet 18-inch iron pipes (weight, 120 pounds per foot), at $3·50	1,225
892 linear feet 24-inch iron pipes (weight, 192 pounds per foot), at $5·25	4,683
Cost of subgrade	171,048

15,000 cross ties, at 50 cents	$7,500
546 long tons 60-pound steel rails, at $48·50	26,481
33,000 pounds (220 kegs, 150 pounds each) spikes, at 2·8 cents	924
64,000 pounds angle bars, at 2·7 cents	1,728
5,000 pounds bolts, at 3·4 cents	170
130 telegraph poles, at $3	390
5,000 pounds telegraph wires, at 4 cents	200
6 miles laying and surface track, at $400	2,400
5 miles of telegraph line to build, at $50	250
1 siding one-half mile long to grade and lay	1,000
Cost of track	41,043
Total cost	212,091
Deduct scrap value of 300 tons of old steel, at $25	7,500
Net cost of rebuilding Southern Pacific	204,591

While in this estimate is included the cost of track material and laying, the Southern Pacific people on account of the advantage this work will bring them, both in bettering their line and in developing the country, ought to, and undoubtedly will, put the track on the subgrade at their own expense, and possibly they will also do a part of the subgrade work. They could well afford to assume the whole expense of reconstruction. The reduction in operating expenses and increased traffic which this scheme, if carried out, will give them would render it a paying investment.

REMOVAL OF THE SANTA FÉ RAILROAD.

That portion of the Atchison, Topeka and Santa Fé line which runs through the reservoir site in Texas is incorporated as the El Paso and Rio Grande railroad, but is popularly known as the Santa Fé, and is so called in this report. This track enters the site near its upper end and traverses its whole length. For the greater part of this distance, the road is in the river bottom on alluvium underlain by quicksand. Reference to the map will show that from a point 2 miles above Canutillo to a point 2 miles below a new channel is forming in close proximity to the track; indeed, for over a mile and a half, it is now only preserved from destruction by heavy riprapping, as the channel is close to the bank. The experience of the Santa Fé people in the valley of the Rio Grande has taught them that the first heavy flood in the river is likely to undermine a good portion if not all of this track and sweep it away; it is, therefore, so far as a permanent track is concerned, highly desirable to get out of the river bottom.

The following is an estimate by sections of the amounts of subgrade work and of required track material. As on the Southern Pacific, where the cuts are of classified material and the adjacent fills must be made of loose rock borrow, only the excess of the fills over the cuts is estimated.

The prices used in figuring the cost are the same as those used for the Southern Pacific work:

Section.	Excavation.			Earth embankment.	Barrow loose rock.	Pile bridge.	Iron pipes.	
	Earth.	Loose rock.	Solid rock.				18-inch.	24-inch.
	Cu. yds.	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*		
1	....	8,485	18,455	....	6,260	....	295	105
2	5,560	14,720	5,240	8,000	35,290	405	90	105
3	....	17,655	61,120	....	2,150	165	225	290
4	....	18,145	21,450	....	102,265	....	....	545
5	....	16,550	16,490	....	65,340	75	70	350
6	16,770	28,540	21,070	....	12,445	255	....	....
7	15,830	14,540	....	38,050	....	315	....	65
8	17,270	13,460	....	41,640	....	285	....	....
9	18,425	14,770	....	43,015	....	240	75	....
10	7,000	....	....	33,165	23,475	360	....	....
11	8,480	....	....	14,410	7,000	120	....	....
12	1,950	....	....	16,510	....	180	....	....
13	4,290	....	....	7,560	....	75	....	....
14	2,330	....	....	5,725	....	120	....	....
15	....	....	....	6,710	....	45	....	....
16	1,340	....	....	11,040	....	150	....	....
17	....	....	....	7,330	....	75	....	....
18	1,740	....	....	6,105	....	45	....	....
Total	90,985	146,865	143,825	239,260	254,225	2,910	755	1,460

Cost of rebuilding 18·2 miles of Santa Fé track.

90,985 cubic yards earth excavation, at 10 cents	$9,098·50
146,865 cubic yards loose rock excavation, at 30 cents	44,059·50
143,825 cubic yards solid rock excavation, at 70 cents	160,677·50
239,260 cubic yards earth embankment, at 10 cents	23,926·00
254,225 yards loose rock, barrow, at 30 cents	76,267·50
2,910 linear feet pile bridge, at $10	29,100·00
755 linear feet, 18-inch iron drain pipe, at $3·50	2,642·50
1,460 linear feet, 24-inch iron drain pipe, at $5·25	7,665·00
Cost of sub-grade	293,436·50
48,100 cross ties, at 50 cents	24,050·00
1,730 long ton, 60-pound steel rails, at $48·50	83,905·00
103,500 spikes, at 2·8 cents	2,898·00
205,400 pounds angle bars, at 2·7 cents	5,545·80
15,700 pounds bolts, at 3·4 cents	533·80
500 telegraph poles, at $3	1,500·00
20,000 pounds telegraph wires, at 4 cents	800·00
18.2 miles of track laying and surfacing, at $400	7,280·00
17 miles telegraph line, at $50	850·00
1 mile of siding, grade and lay	2,000·00
Cost of track	129,362·60
Total	422,799·10
Deduct 1,500 tons of old steel, at $25	37,500·00
Net cost of removing Santa Fé railroad	385,299·10

On neither the Santa Fé nor the Southern Pacific will any depot buildings have to be abandoned; hence none will have to be built.

SUMMARY OF COST.

Cost of site of reservoir	$69, 100 ·00
Cost of dam	304, 369 ·00
Cost of moving Southern Pacific railroad	204, 591 ·00
Cost of moving Santa Fé railroad	385, 299 ·10
Total	963, 359 ·10
Add 10 per cent for administration and incidentals	96, 335 ·91
Grand total	1, 059, 695 ·01

It is customary to add to preliminary estimates of work of this kind 15 per cent. If it were an estimate of cost of the dam alone that amount would be added, but nearly two-thirds of the total cost is for moving the railroads and there is very little uncertainty about the estimate for that work; so that in Mr. Follett's judgment 10 per cent is enough to add. If the railroad companies will furnish and lay their own track it will reduce this total to $921,751·05.

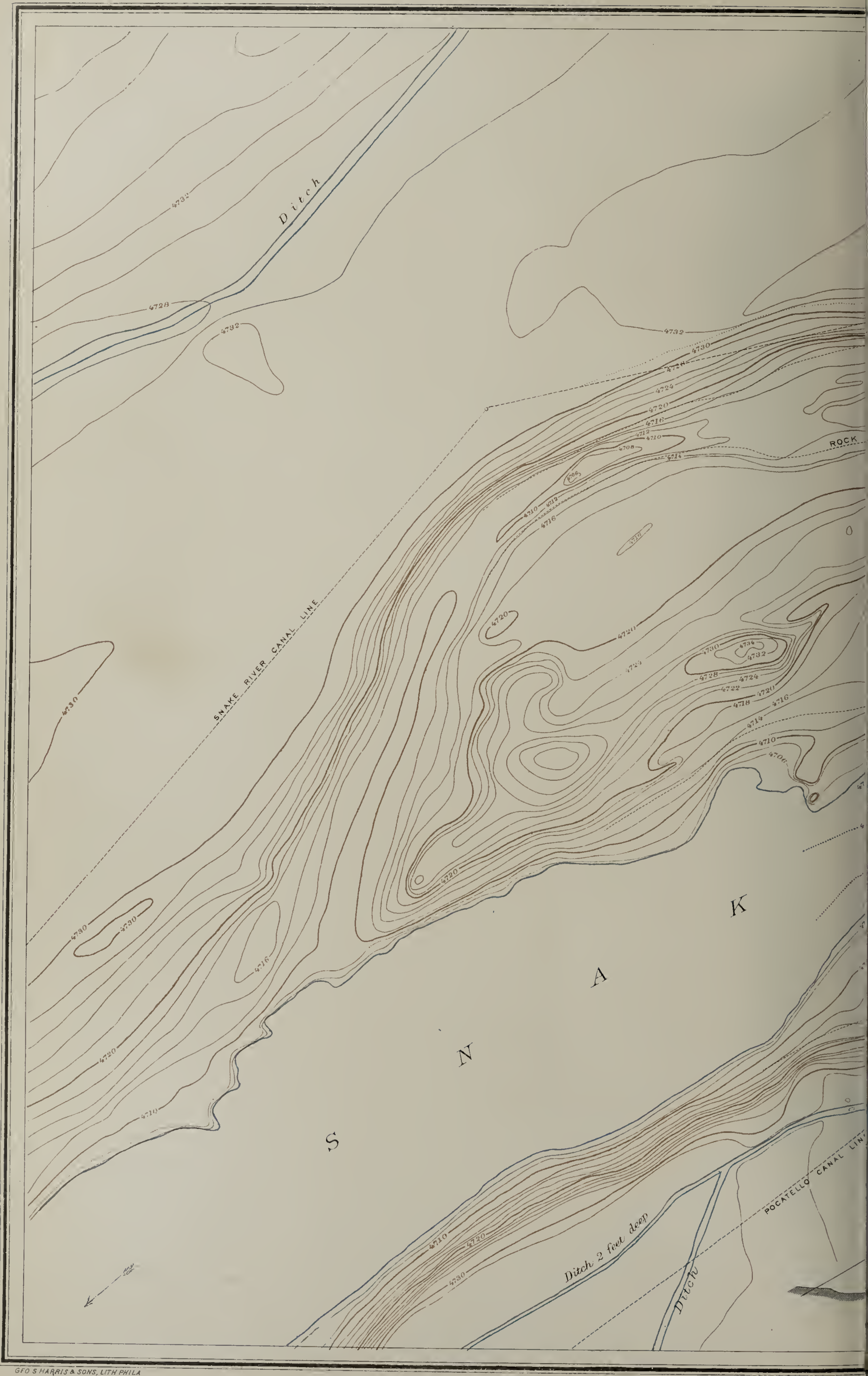
POCATELLO CANAL, IDAHO.

In the southwestern portion of Idaho, in Bingham county, is the beginning of the great Snake river, formed by the junction of its North and South forks a short distance above Eagle rock. Below these forks the river flows through a great plain several hundred miles long and 100 miles wide, the soil of much of which is of excellent agricultural quality and produces abundant and rich crops of hay, grain, vegetables, and all the temperate zone fruits when supplied with water.

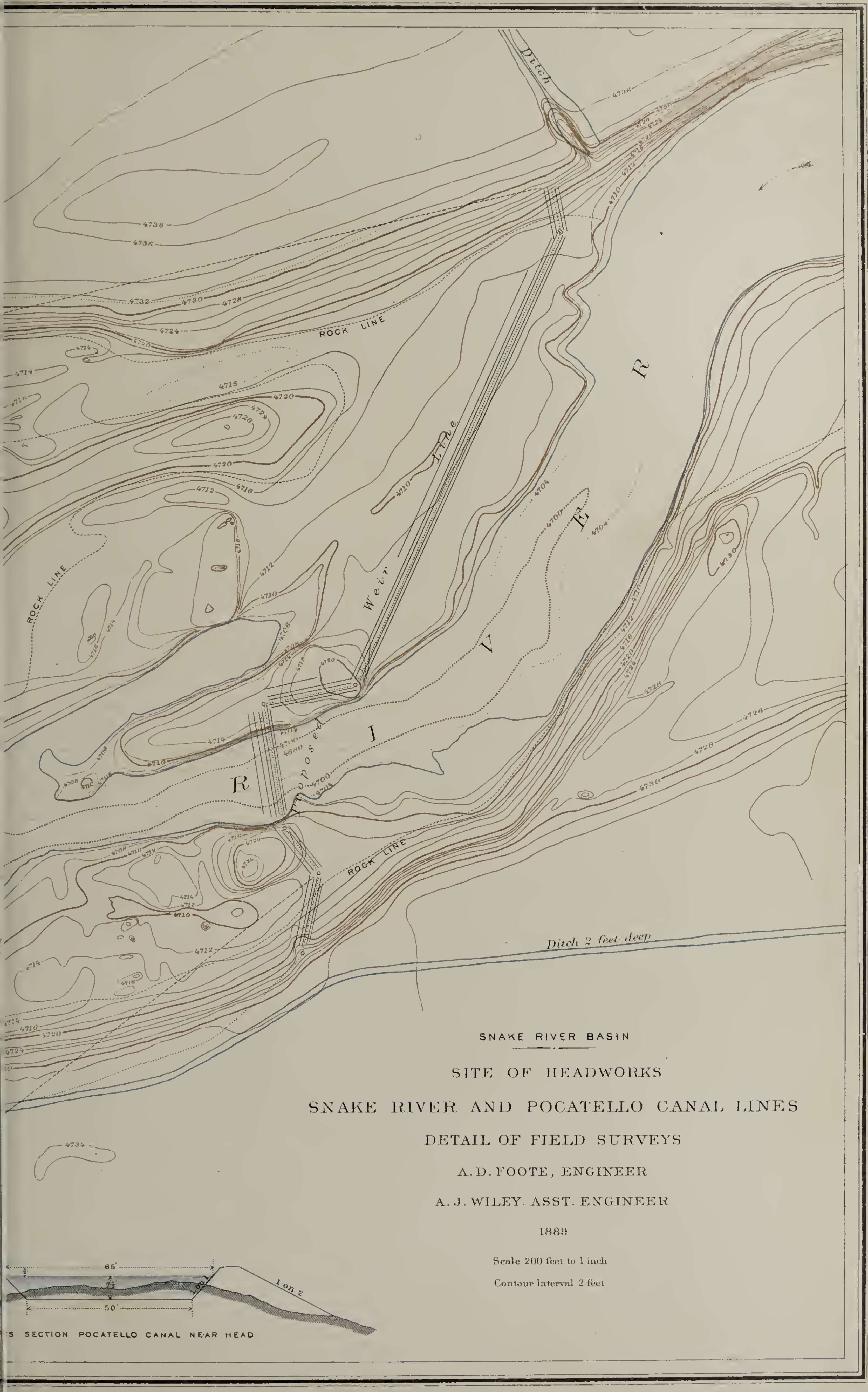
The discharge of the Snake river at Eagle rock is large, amounting to 1,500,000 acre-feet per annum, the least recorded discharge being 2,300 second-feet late in the summer of 1889, though it rarely falls below 4,000 second-feet.

In the summer of 1889 surveys were made by Mr. A. D. Foote, irrigation engineer of the U. S. Geological Survey, to determine the feasibility of irrigating certain valley lands on the south side of the Snake river in the southern half of Bingham county and the northern portion of the Fort Hall Indian reservation. This survey was started at a point on the Snake river about 1½ miles south of the town of Eagle rock in the SE. ¼ of SW. ¼ of sec. 25 of T. 2 N., R. 37 E. of Boise meridian, at an exceptionally favorable site for the location of headworks for the diversion of the waters of the Snake river. These headworks, as at present planned, will consist of a rock-fill dam 185 feet long, with a maximum height above the bed of the river of 55 feet, and a wasteweir of masonry about 900 feet in length, with a maximum height of 15 feet. The piers of the headgates, the masonry abutments of the rock-fill dam and the wasteweir will all be built upon solid rock foundations above the height of ordinary water in the river. The same headworks are to be used for a canal from the north side of the river. (Pl. CLXXXII.)

The cross-section adopted for the first section of the Pocatello canal



GEO S HARRIS & SONS, LITH PHILA



SNAKE RIVER BASIN

SITE OF HEADWORKS

SNAKE RIVER AND POCATELLO CANAL LINES

DETAIL OF FIELD SURVEYS

A. D. FOOTE, ENGINEER

A. J. WILEY. ASST. ENGINEER

1889

Scale 200 feet to 1 inch

Contour Interval 2 feet

has a bottom width of 50 feet, side slopes of one to one, and a water depth of 7½ feet. The elevation of the bottom of the canal at the headgates is 4,717 feet above sea level as determined by the level of the Utah and Northern railway. The grade rate is 0·3 per cent, which gives a calculated velocity of 3·46 feet per second, and a discharge of 1,492 second-feet. For the first mile of its course the canal will follow the bank of the river closely, with a cut about 12 feet in depth. Thenceforth it continues very nearly at grade to the crossing of the Utah and Northern railway, whence it continues on a very level country with little or no bad cut or fill work to the end of the fifteenth mile, where it strikes the foothills and follows them until the Blackfoot river is reached. At this point the canal turns abruptly and runs almost due east up the Blackfoot river as far as the ranch of N. A. Just, at the end of the twenty-second mile from the head.

Here the bottom grade of the canal is 36 feet above the Blackfoot river, which is distant about 700 feet. Extending from the line of canal to the river is a lava bench with a fall of 1 foot to the 100 from the canal to a point 20 feet from the river, where there is an almost vertical fall of 29 feet. Over this lava bench it is proposed to drop the canal into the Blackfoot. To carry the canal farther up would be impracticable on account of the lava bluffs which border the north side of the river above, and useless, because the land in the valley can be watered from the river.

The Blackfoot river, which the canal line follows for the next 16 miles of its course, has an average width of 50 feet, with banks 8 feet high, and an average fall of 5·6 feet per mile. It follows very closely the foothills of the Portneuf range, and is bordered on both sides by shifting sand hills. In July, 1889, this river was carrying about 30 second-feet of water near Just's ranch, but the greater part of this was taken out a few miles below by the Eastern Idaho Ditch company for irrigation in the vicinity of the town of Blackfoot.

A meander survey in connection with a line of levels was made of the Blackfoot river from the point of convergence with the canal near the end of the twenty-second mile to the point of divergence beyond the thirty-eighth mile. No improvements will be needed in the river bed to make it capable of carrying the water of the canal. The velocity of flow due to the fall of 5·6 feet per mile will be checked by the very crooked channel, while the banks are protected from erosion by a dense growth of willows, and the river bed is formed of a very stiff clay.

The canal leaves the river at a point about 3 miles southeast of the town of Blackfoot and 38½ miles by the line from the head of the canal on Snake river. The diversion of the canal from the Blackfoot will be effected by a masonry weir across the river, connected by earth dikes with the high ground on each side of the river.

The water section of the canal between the Blackfoot and Portneuf rivers will be 30 feet wide on the bottom, with side slopes of one to one and a depth of 7 feet, giving, with a grade of 0·3 per 1,000 feet, a velocity of 3·19 feet per second and a discharge of 939 second-feet. The line follows closely the base of the foothills of the Portneuf range, upon very favorable ground, to Ross creek, which it reaches at the end of its fifty-fourth mile. The only possible difficulty that may be encountered in the construction of this section of the canal, between the Blackfoot river and Ross creek, would be the lightness of the soil, which in places consists almost entirely of sand. These places, however, are neither numerous nor of great extent, and the sand is probably underlain by soil of greater consistency. Ross creek is an unimportant stream, and in the summer of 1889 was almost entirely dry. It flows in a deep narrow channel, and will be passed under the canal by a culvert.

After crossing Ross creek the line runs through partially cultivated lands belonging to the Indians of the Fort Hall reservation, and insufficiently watered by a ditch taking water from Ross creek. The canal now runs on an almost perfect "grade line" until the Indian ditch is crossed, about 55·4 miles from the head of the canal on Snake river.

From the point where the grade line is again in a uniform country to near the sixtieth mile, the line runs almost parallel to the Utah and Northern railway, and not far from it, to the sixty-fifth mile. For the next mile a heavy cut, reaching at one point a depth of 18 feet, is rendered necessary by the Utah and Northern railway, which here crosses the long gently sloping bench formed by Pocatello creek. This cut can be avoided only by raising the grade of the railway at two points sufficiently to allow the passage of the canal beneath it. Henceforth the line runs "on grade," diagonally across the eastern half of the new townsite of Pocatello, to the seventieth mile, where it drops over a lava bench into the Portneuf river, making a fall of 14 feet between the bottom of the canal and the bottom of the river. The Portneuf at this point is a stream about 50 feet wide with banks 8 feet high. For the next 1,000 feet the canal will follow the Portneuf river, and so avoid an independent crossing of the Oregon Short Line railway. The canal will be diverted from the Portneuf at this point by a masonry weir across the river. The water section of the canal will now have a bottom width of 16 feet with side slopes of one to one, and a depth of 5 feet, which, with the grade of 0·3 per 1,000 feet, gives a discharge of 249 second-feet.

For 7 miles below the point of diversion the canal follows closely the Portneuf river. About 6 miles of this work is upon a nearly level cross-section, and presents no features of difficulty or interest, but from the seventy-sixth to the seventy-seventh mile the line is located upon a side hill whose slopes run from 25 degrees to 45 degrees from the horizontal. Much of this side hill is covered with broken rock from the cliffs above, making this portion of the line a very expensive one. The work on the line beyond this point is heavier than necessary, because the line was located for a large canal to be carried down the river as far as Goose creek valley, and a more direct alignment was made than would be necessary for a canal of the small section finally adopted. After crossing the Oregon Short Line railway to the north side the line runs nearly at grade across a very regular country to the eighty-sixth mile, where it recrosses the railroad. After this the canal cuts through a sharp ridge and enters the valley of Bannock creek up which it runs for about 2 miles before crossing it. Bannock creek is a small stream running in a deep narrow channel, and can easily be passed under the canal by a culvert. Nearly all of its water is used by the Indians for irrigation. The canal now runs across and down this valley near grade to the ninety-first mile, where the Oregon Short Line is again crossed on a heavy cut; after which the line keeps closely on grade to the end of the ninety-third mile, where the section is again reduced.

The new section has a bed width of 10 feet, a depth of 4 feet, with side slopes one to one, giving a velocity of 2·37 feet per second and a discharge of 105 second-feet. The canal now runs on a level country with very light work, for the remainder of its course to its terminus on the north bank of Dry gulch is not high enough to follow the base of the foothills, and leaves uncovered a strip of land between the canal and the foothills amounting to about 18,000 acres. This land can be covered only by a small canal taken out of the Portneuf river some miles above the point where the present line leaves it.

Between the head of the canal and the Blackfoot river there are 74,480 acres of land beneath the canal. Between the Blackfoot and the Portneuf rivers there are 107,200 acres, and between the Portneuf and American falls there are 34,720 acres, making a total of 216,400 acres of reclaimable land, all of which has an exceptionally fine soil. Of this land 141,000 acres are on the Fort Hall Indian reservation, and the remaining 75,400 only are open to settlement.

As shown by the detailed estimates accompanying this report, the total cost of a main canal to cover this 216,400 acres will be $439,764, while the 181,680 acres north of the Portneuf river can be covered for $343,193, or less than $2 per acre. If the headworks of this canal should be used, as is proposed, for a canal on the north side of the Snake river, the cost of reclaiming the 181,680 acres north of the Portneuf will be reduced to $294,190, or $1.50 per acre, while the whole tract of 216,400 acres could be covered for $390,760, or $1.80 per acre.

The total quantities of excavation for this canal line will be as follows:

Section.	Length.	Earth.	Loose rock.	Solid rock.	Total material.
	Miles.	*Cu. Yds.*	*Cu. Yds.*	*Cu. Yds.*	*Cu. Yds.*
Eagle rock to Blackfoot river	22	1,086,069	....	....	1,086,069
Blackfoot to Portneuf river	49	1,116,650	....	1,470	1,118,120
Portneuf river to Bannock creek	23	546,675	45,965	2,050	594,690
Baunock creek to Dry creek	7	92,960	....	....	92,960

STRUCTURES.

Section 1.

Head works.—17,650 cubic yards loose rock excavated and placed in dam; 1,575 cubic yards masonry in piers; 1,730 cubic yards masonry in abutments; 1,860 cubic yards masonry in waste weir; headgates and building estimated at $5,000; 1 railroad bridge; 5 wagon bridges.

Section 2.

Six wagon bridges; culvert at Ross creek, 120 feet long, 2 feet diameter; weir in Blackfoot river, 500 cubic yards masonry.

Section 3.

Three railroad bridges; 4 wagon bridges; culvert at Bannock creek, $2,000; weir in Portneuf river, 500 cubic yards masonry.

Section 4.

Two railroad bridges; three wagon bridges.

Estimated cost of section 1.

17,650 cubic yards loose rock placed in dam, at $1·75	$30,887
1,730 cubic yards masonry in abutments, at $7	12,110
1,575 cubic yards masonry in piers, at $7	11,025
7,860 cubic yards masonry, waste-weir, at $7	55,020
Headgates and building	5,000
1,086,070 cubic yards earth, at 10 cents	108,607
10,000 feet, B. M., of lumber in railroad bridge, at $40 per M	400
400 linear feet of piling, in railroad bridge, at 35 cents	140
26,000 feet, B. M., of lumber in wagon bridges, at 35 cents per foot	910
1,350 linear feet piling in wagon bridges, at 35 cents	473
Total	224,572

Estimated cost of section 2.

1,116,650 cubic yards earth, at 10 cents	$111,665
1,470 cubic yards loose rock, at 50 cents	735
24,000 feet, B. M., of lumber in wagon bridges, at $35 per M	840
1,260 linear feet of piling in wagon bridges, at 35 cents per foot	441
120 linear feet of culvert, 2 feet diameter, at $12 per M	1,440
500 cubic yards of masonry, at $7	3,500
Total	118,621

Estimated cost of section 3.

546,675 cubic yards of earth, at 10 cents	$54,668
45,965 cubic yards of loose rock, at 50 cents	22,982
2,050 cubic yards of solid rock, at $1	2,050
18,000 feet, B. M., of lumber in railroad bridges, at $40 per M	720
720 linear feet of piling in railroad bridges, at 35 cents per foot	252
10,000 feet, B. M., of lumber in wagon bridges, at $35 per M	350
200 linear feet of piling in wagon bridges, at 35 cents per foot	70
Culvert at Bannock creek	2,000
500 cubic yards masonry at weir in Portneuf river, at $7	3,500
Total	86,592

Estimated cost of section 4.

92,960 cubic yards of earth, at 10 cents	$9,296
8,000 feet, B. M., of lumber in railroad bridges, at $40 per M	320
360 linear feet of piling in railroad bridges, at 35 cents per ft	126
5,850 feet, B. M., of lumber in wagon bridges, at $35 per M	205
90 linear feet of piling in wagon bridges, at 35 cents	32
Total	9,979

RECAPITULATION.

Section 1, Eagle Rock to Blackfoot river	$224,572
Section 2, Blackfoot to Portneuf	118,621
Section 3, Portneuf to Bannock creek	86,592
Section 4, Bannock creek to Dry gulch	9,979
	439,764

DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY.

REPORT

UPON THE

CONSTRUCTION OF TOPOGRAPHIC MAPS, AND THE SELECTION AND SURVEY OF RESERVOIR SITES IN THE HYDROGRAPHIC BASIN OF THE ARKANSAS RIVER, COLORADO.

BY

A. H. THOMPSON.

REPORT UPON THE CONSTRUCTION OF TOPOGRAPHIC MAPS, AND THE SELECTION AND SURVEY OF RESERVOIR SITES IN THE HYDROGRAPHIC BASIN OF THE ARKANSAS RIVER IN COLORADO.

By A. H. Thompson.

TOPOGRAPHIC MAPS.

That part of the hydrographic basin of the Arkansas river within the limits of the state of Colorado lies between the meridians 102° and 106° 30′ west longitude, and 37° and 39° 30′ latitude, and embraces an area of approximately 29,350 square miles.

A topographic survey of this region was commenced by the parties of the U. S. Geological Survey under the immediate charge of Mr. Willard D. Johnson, in September, 1889, and the work, both field and office, practically completed in June, 1891.

This survey was undertaken primarily for the purpose of discovering and locating the reservoir sites within the drainage basin, the catchment area tributary to each reservoir site, the situation and area of irrigable lands, and to indicate in a closely approximate way the possible location of canal lines to conduct the waters from the reservoirs to the lands.

To give this data, maps were constructed on a scale of 1:125,000, or 2 miles to the inch, nearly; the relief being shown by contour lines of equal altitudes having an interval of 100 feet in the mountainous country, 50 feet in the less rugged country, and 25 feet in the plains region. In some cases all these contour intervals appear on the same sheet.

The maps were constructed by atlas sheet areas embracing 30 minutes each way in latitude and longitude, conforming to the general plan for the Topographic Atlas of the United States, in the process of construction by the U. S. Geological Survey.

The field work was done by plane table methods, the horizontal control being primarily based on the stations of the transcontinental triangulation of the U. S. Coast and Geodetic Survey, the primary stations in the triangulation of the U. S. Geological Survey of the territories, under Dr. F. V. Hayden, and the triangulation of the U. S.

Geological Survey either computed or graphic from these stations. The vertical control was based upon the altitudes furnished by the levels of the railroad lines within the basin as adjusted in Gannett's Dictionary of Altitudes. From these base lines others were run to important control points, and to these bench marks were referred all the altitudes determined.

The altitudes of most minor points were determined by angular leveling, though the aneroid barometer was extensively used during the first season's work. Most of the drainage lines and cliff edges of mesas were traversed, as were all public roads.

All sketching of topographic forms was done on the plane table. During the first year the work was done on the small traverse plane tables and transferred to the final sheets, but afterwards all work was done on plane table sheets the full size of an atlas sheet, and all the drawing, except the lettering and final inking, done in the field ready for the engraver. At least two and often five or six points in the primary triangulation were located both in plane and in altitude on each atlas sheet, and used as reference points for all the succeeding work. In the foothills and plains region these reference points were all permanently marked.

The field and office work was usually done on twice the scale intended for publication. Owing to great changes in the topographic features on the same atlas sheet, it was necessary to adopt different contour intervals on the same sheet in order to express the topography in a way to subserve the purposes of the maps. A small interval was necessary in the gently sloping regions in order to show the declivity of the irrigable lands and the approximate location of canal lines. In these regions 25 feet was adopted. It was not possible to carry this interval into the representation of the cliffs and steeper mountain slopes; so in these regions the intervals of 50 or 100 feet was adopted, varying, of course, with the steepness of the country. In order clearly to represent these changes of contour interval on the same sheet, the engraver cut the lines of different widths or weights, the contours representing each thousand feet of elevation being the broadest, the lines representing each hundred feet change in elevation next less in width, and contours representing a change of interval of 25 feet the thinnest. Where the engraver executed the terms of his contract the result is excellent.

The maps are all engraved on copper, three plates being required for each atlas sheet, the first showing the contours, the second the drainage lines, and the third the culture. These are printed in different colors, the contours being in brown, the drainage or water in blue, and the culture in black.

In all 30 full atlas sheets and 10 fractional parts of atlas sheets were necessary to represent the drainage basin of the Arkansas river in Colorado.

The atlas sheets are named usually from the most important town within their limits, though sometimes from some prominent natural features.

The following table gives the designation of all atlas sheets included in the drainage basin of the Arkansas river in Colorado, the latitude and longitude of the southeast corner, and the contour interval upon each sheet.

Name of sheet.	Southeast corner.		Contour interval.	Remarks.
	Latitude.	Longitude.		
	° ′ ″	° ′ ″	*Feet.*	
Leadville	39 00 00	106 00 00	25 50 100	Full atlas sheet.
Pikes peak	38 30 00	105 00 00	25 50 100	Do.
Canyon city	38 00 00	105 00 00	25 50 100	Do.
Huerfano park	37 30 00	105 00 00	25 50 100	Do.
Castle rock	39 00 00	104 30 00	25 50 100	Do.
Colorado Springs	38 30 00	104 30 00	25 50 100	Do.
Pueblo	38 00 00	104 30 00	25 50	Do.
Walsenburg	37 30 00	104 30 00	25 50 100	Do.
Trinidad	37 00 00	104 30 00	25 50 100	Do.
Big Springs	38 30 00	104 00 00	25 50	Do.
Nepesta	38 00 00	104 00 00	25	Do.
Apishapa	37 30 00	104 00 00	25	Do.
El Moro	37 00 00	104 00 00	25 50 100	Do.
Limon	39 00 00	103 30 00	25 50	Do.
Sanborn	38 30 00	103 30 00	25	Do.
Catlin	38 00 00	103 30 00	25	Do.
Timpas	37 30 00	103 30 00	25	Do.
Mesa de Maya	37 00 00	103 30 00	25 50 100	Do.
Arroyo	38 30 00	103 00 00	25	Do.
Las Animas	38 00 00	103 00 00	25	Do.
Higbee	37 30 00	103 00 00	25 50	Do.
Mount Carrizo	37 00 00	103 00 00	25 50 100	Do.
Kit Carson	38 30 00	102 30 00	25	Do.
Lamar	38 00 00	102 30 00	25	Do.
Two Buttes	37 30 00	102 30 00	25	Do.
Springfield	37 00 00	102 30 00	25	Do.
Cheyenne Wells	38 30 00	102 00 00	25	Do.
Granada	38 00 00	102 00 00	25	Do.
Albany	37 30 00	102 00 00	25	Do.
Vilas	37 00 00	102 00 00	25	Do.
Aspen	39 00 00	106 30 00	50 100	Fractional atlas sheet.
Saguache	38 30 00	106 30 00	50	Do.
Buena Vista	38 30 00	106 00 00	50 100	Do.
Marshall pass	38 00 00	106 00 00	50 100	Do.
Arkansas hills	38 30 00	105 30 00	25 50 100	Do.
Rito Alto	38 00 00	105 30 00	50 100	Do.
Crestone	37 30 00	105 30 00	50 100	Do.
Culebra	37 00 00	105 00 00	50 100	Do.
Kiowa	39 00 00	104 00 00	25	Do.
Hugo	39 00 00	103 00 00	25	Do.

From these maps a second map on the scale of 6 miles = 1 inch was compiled. This map includes only the drainage basin of that part of the Arkansas river lying in the state of Colorado.

The topography is represented by contour lines having an interval of 100 feet in the plains region and 200 feet in the mountains. It also shows the principal streams, the larger towns, all surveyed reservoir sites, the boundaries of the tributary drainage basin, and the township lines of the Land Survey.

TOPOGRAPHY.

The hydrographic basin of the Arkansas river in Colorado presents three well defined areas of distinct types of topographic forms—mountains, mesas, and plains.

The mountain area comprises the western third. It rises abruptly from the eastern plains and mesa regions, often in a bold escarpment thousands of feet in height, then rolls back a gradually rising region of mountain ranges, isolated peaks, deep canyons, and beautiful valleys to the western rim of the basin.

Through this region the Arkansas river flows first in a southern, then in an eastern direction, dividing it into two almost equal parts. The upper and northern part of its course is in a mountain valley, too elevated for much cultivation of the soil, except near its southern extremity. Its lower course is in close canyons, with walls often rising almost vertically 3,000 feet. The western rim of the basin is formed by three of the loftiest ranges in Colorado, the Sawatch, Sangre de Christo, and Culebra, each having summits over 14,000 feet in altitude.

These ranges stretch in an irregular double curve southeastwardly from Tennessee pass on the north to the Boundary mountains, just below the dividing line between Colorado and New Mexico.

The northern rim of the basin is less imposing from contrast with its western rival. Having the same point of origin (Tennessee pass) as the western rim, it swings in the arc of a great circle down the crest of the Park range round the Arkansas hills by Chalcedony butte to the junction of the Rampart range with the Arkansas divide, which forms the crest between the watersheds of the South Platte river and Monument creek.

The eastern rim has a general north and south trend broken by a deep reentrant angle of mesa type of topography where it crosses the Arkansas river. Like the northern, it is less continuous as a mountain wall than the western rim.

The Rampart range, forming the rim north of the Arkansas river, rising abruptly from the plains and having the great mass of Pike's peak at its southern extremity, is, however, as imposing as any of the western ranges. South of the Arkansas river the Wet mountains range forms the rim until they merge into the Spanish peaks and the eastern flank of the Culebras.

The region included within these mountain walls is in the shape of an irregular triangle, its apex in Tennessee pass and its base the whole eastern rim. It comprises an area of approximately 28,600 square miles.

The Arkansas river, flowing first in a southern and then in an eastern direction, divides this region into two nearly equal parts. Its upper and southern course is in an open valley, but its lower and eastern is in deep canyons, having, sometimes, walls 3,000 feet in height.

It descends from the lofty summits of the western ranges to an altitude of 4,600 feet, where it enters the mesa country below Canyon city, a distance of 120 miles.

West and south of the river their slopes are steeper; the drainage tributary streams are more numerous than on the east and north.

The whole region is one of great precipitation and is the principal source of the water which the river bears to the plains.

The mesa region extends from the mountains eastward into the plains. It also forms a prominent feature in the southern part of the basin. Definite limits can hardly be given to this region, as it gradually takes its distinctive features from the foothills of the mountain ranges and as gradually merges into the plains. Its mesas or tables range in altitude from 5,000 feet along the Arkansas river to 9,000 feet near the New Mexico line.

The mesa region is more pronounced in type and greater in area in the southern part of the drainage basin than the northern.

The plains region occupies by far the larger part of the drainage basin of the Arkansas river in Colorado, extending from the mesas to the eastern boundary of the state.

It is divided into two nearly equal parts by the Arkansas river, which throughout has a nearly direct eastern course and forms the dividing line between two areas quite distinct in topographic details.

The altitude of the immediate valley of the river is 4,650 feet at Pueblo, near the western limit of the region, and 3,350 feet at the eastern boundary of the state, a distance of approximately 150 miles by river. It is for the most part a narrow flood plain, lying but a few feet above the surface of the water, and bounded by well defined bluffs on either side.

North of the river the country gradually rises from the bluff line to the divide between the Arkansas and the South Platte and Republican rivers.

This slope has its greatest altitude at its western edge and decreases to the eastern boundary of the state, thus giving a general slope of the whole area towards the southeast, and this is also the usual direction of its drainage lines.

It is a region scantily supplied with water, having no permanent streams, though the principal drainage lines carry water during the early spring months, and in the rainy months of summer are often raging torrents. These waterways have wide valleys with short lateral branches, thus leaving broad, gently undulating areas between considerable drainage lines.

Quite frequently these undulating plateaus do not drain into adjacent valleys, but into depressions on their surfaces. Some of these depressions are of large extent.

South of the Arkansas valley the topography is more broken, but still presents the general features of a great rolling plain, sloping towards the north and east and cut diagonally across by drainage lines having a general northeasterly course.

The streams of these waterways are often in canyons, sometimes having walls 600 to 800 feet in height. This is more especially the case in the central portion of the area.

RESERVOIR SITES.

Instructions were given to the topographers engaged in field work to devote special attention to the discovery and location of all possible reservoir sites within the area surveyed by them, to the location of irrigable lands, and to the extent and classification of forest growth, distinguishing between the forests valuable for lumber and those valuable for firewood, fencing, and other domestic purposes.

One hundred and forty-seven possible reservoir sites were reported. Some of these were small, some were commanded by others more favorably situated to control to best advantage the waters of the given drainage basin, but all were given examination, and from the whole number reported forty-six were selected as being so located as to completely store all the waters of the basin, and as being most favorable situations in regard to the irrigable lands.

These sites were then surveyed to determine the best location for a dam, its height, the area that would be covered by water at the given height of dam, the approximate content of the reservoir and the subdivisions of the Land Survey embraced within its limits. The field work was done with telescopic alidade, level, and stadia rods.

In addition to the forty-six reservoir sites surveyed by the topographers, nine were reported and surveyed by the engineering section of the Irrigation Survey, making fifty-five in all.

The nine sites surveyed by the engineering section and numbered 1, 2, 3, 4, 5, 7, 25, 38, and 39 respectively, are not included in this report, having been described in the report of Mr. H. M. Wilson on engineering work in Colorado.

Of the forty-six reservoir sites surveyed, twenty-five are in the mountain region and twenty-one in the mesa and plains regions.

Three of the sites, numbers 44, 45, and 46 are so situated that they have practically no catchment area. They could, however, be easily filled by high line canals from the Arkansas river. All the others have drainage basins of considerable extent, generally large enough to fill the reservoir.

A short description of each reservoir site is submitted.

A more detailed report of the survey of these reservoir sites was published in part 2 of the Twelfth Annual Report of the Director of the U. S. Geological Survey, an abstract from which is here given.

RESERVOIR SITE NO. 6.

Is situated in Chaffee county, Colorado, on Sevenmile creek, near junction with Arkansas river.

Drainage area about 30 square miles, extending from crest of Park range nearly to Arkansas river. Lightly wooded on higher slopes. Streams have intermittent flow above and continuous but light flow through reservoir site.

Altitude, 8,400 feet.

Area of reservoir site, 160 acres.

Approximate capacity, 4,550 acre-feet.

RESERVOIR SITE NO. 8.

Is situated in Custer county, Colorado, on Grape creek, at northern end of the Wet mountain valley.

Drainage area about 380 square miles, bordered by the crest of the Sangre de

Cristo range for 26 miles, and by the Greenhorn range for 14 miles. Heavily timbered over a small area, lightly wooded over a quarter of the area, and bare of timber over two-thirds of the area. The main stream has strong, continuous flow. Many of the tributaries are intermittent, but furnish large quantities of water during periods of floods.

Altitude, 8,000 feet.

Area of reservoir site, 2,540 acres.

Approximate capacity, 119,100 acre-feet.

RESERVOIR SITE NO. 9.

Is situated in Fremont county, on Pine creek, 3 miles above junction with Grape creek.

Drainage area about 30 square miles, in wooded hills. Stream has light continuous flow.

Altitude, 7,900 feet.

Area of reservoir site, 80 acres.

Approximate capacity, 1,520 acre-feet.

RESERVOIR SITE NO. 10.

Situated in Park and El Paso counties, Colorado, on Slate creek, just above junction with West Oil creek.

Drainage area about 25 square miles in wooded hills. Stream has light continuous flow.

Altitude, 8,100 feet.

Area of reservoir site, 560 acres.

Approximate capacity, 8,570 acre feet.

RESERVOIR SITE NO. 11.

Situated in Park county, Colorado, on West Oil or Ten mile creek.

Drainage area about 20 square miles. Heavily timbered. Streams have light continuous flow.

Altitude, 8,500 feet.

Area of reservoir site, 200 acres.

Approximate capacity, 2,150 acre-feet.

RESERVOIR SITE NO. 12.

Is situated in El Paso county, Colorado, on Oil creek, at junction with West Oil creek.

Drainage area of about 160 square miles, extending northward to the divide between the Arkansas and Platte basins. Well wooded, with some heavy timber. Streams have continuous flow.

Altitude, 8,500 feet.

Area of reservoir site, 1,400 acres.

Approximate capacity, 56,200 acre-feet.

RESERVOIR SITE NO. 13.

Is situated in El Paso county, Colorado, on West Beaver creek, near junction with Beaver creek.

Drainage area of about 60 square miles, extending back to the high ridges about Pike's peak. Heavily wooded. Continuous flow in streams.

Altitude, 9,000 feet.

Area of reservoir site, 1,320 acres.

Approximate capacity, 28,450 acre-feet.

RESERVOIR SITE NO. 14.

Is situated in El Paso county, Colorado, on Beaver creek, near junction with West Beaver creek.

Drainage area of about 25 square miles, extending back to Pike's peak. Heavily timbered. Streams have continuous flow.

Altitude, 9,000 feet.

Area of reservoir site, 50 acres.

Approximate capacity, 620 acre-feet.

RESERVOIR SITE NO. 15.

Is situated in Fremont county, Colorado, on Oil creek, about 10 miles above junction with Arkansas river.

Drainage area of about 270 square miles. A semimountainous, well wooded region, with narrow valleys and little agricultural land, extending from Pike's peak westward to the Arkansas hills. Oil creek and its larger branches have continuous flow.

Altitude, 5,800 feet.

Area of reservoir site, 167 acres.

Approximate capacity, 4,300 acre-feet.

RESERVOIR SITE NO. 16.

Is situated in Fremont county, Colorado, on Wilson creek, just above junction with Oil creek.

Drainage area about 35 square miles; mountainous and partly wooded; intermittent flow.

Altitude 5,900 feet.

Area of reservoir site, 80 acres.

Approximate capacity 2,900 acre-feet.

RESERVOIR SITE NO. 17.

Is situated in Fremont county, Colorado, on Sand creek, just west of Canyon city, and a little above junction of Sand creek with the Arkansas river.

Drainage area about 30 square miles; wood all cut off; intermittent flow to streams.

Altitude, 5,450 feet.

Area of reservoir site, 115 acres.

Approximate capacity 1,950 acre-feet.

RESERVOIR SITE NO. 18.

Is situated in Fremont county, Colorado, on Six mile creek, about 6 miles above junction with Arkansas river.

Drainage area of about 10 square miles in the Six mile creek basin, and, by diversion, from the Eight mile creek basin, 50 square miles, and from the Beaver creek basin 120 square miles. All well wooded and rising in elevation northward to the high ridges about Pike's peak. Intermittent flow through site.

Altitude, 5,500 feet.

Area of reservoir site, 50 acres.

Approximate capacity, 3,100 acre-feet.

RESERVOIR SITE NO. 19.

Is situated in Fremont county, Colorado, on Eight mile creek, in foothills.

Drainage area about 50 square miles, in high foothills. Upper portion lightly wooded. Stream intermittent.

Altitude, 5,500 feet.

Area of reservoir site, 210 acres.

Approximate capacity, 4,540 acre-feet.

RESERVOIR SITE No. 20.

Is situated in Fremont and Pueblo counties, Colorado, on Beaver creek, near its junction with the Arkansas river.

Drainage area of about 130 square miles, extending from Pikes peak to the Arkansas river. For the upper 25 miles it receives tributaries from a mountainous and well timbered region. The main stream and several of its branches have continuous flow.

Altitude, 5,100 feet.

Area of reservoir site, 215 acres.

Approximate capacity, 7,100 acre-feet.

RESERVOIR SITE No. 21.

Is situated in Pueblo county, Colorado, on Turkey creek, just outside of foothills, in a region of low mesas.

Drainage area of about 70 square miles, extending back to the higher ridges of the Pike's peak group. The mountainous portion is well wooded. Turkey creek has a light, continuous flow.

Altitude, 5,400 feet.

Area of reservoir site, 520 acres.

Approximate capacity, 9,800 acre-feet.

RESERVOIR SITE No. 22.

Is situated in Pueblo county, Colorado, on Turkey creek, just above junction with Arkansas river.

Drainage area of about 70 square miles, one-half mountainous and one-half plains. Mountainous portion lightly wooded. Streams have usually a continuous flow.

Altitude, 5,000 feet.

Area of reservoir site, 90 acres.

Approximate capacity, 1,920 acre-feet.

RESERVOIR SITE No. 23.

Is situated in Pueblo county, Colorado, on the Arkansas river, 8 miles west of Pueblo.

Drainage area, all the mountainous portion of the river basin directly tributary to the river.

Altitude, 4,840 feet.

Area of reservoir site, 1,920 acres.

Approximate capacity, 359,000 acre-feet.

RESERVOIR SITE No. 24.

Is situated in Pueblo county, Colorado, on Rush creek, on high broken plains, near the foothills.

Drainage area, 10 square miles on Rush creek basin, and, by diversion, portions of the drainage of the Red creek and Peck creek basins, which extend back into the foothills and are subject annually to floods. Rush creek has uncertain, intermittent flow.

Altitude, 5,400 feet.

Area of reservoir site, 335 acres.

Approximate capacity, 2,100 acre-feet.

RESERVOIR SITE NO. 26.

Is situated in Pueblo county, Colorado, on St. Charles river, about midway from source to junction with Arkansas river, on the high plains.

Drainage area about 180 square miles, extending back 30 miles to the crest of the Greenhorn range. Heavily timbered on mountain slopes, with small quantity of light wood in foothills. Stream has continuous flow.

Altitude, 4,980 feet.

Area of reservoir site, 170 acres.

Approximate capacity, 2,640 acre-feet.

RESERVOIR SITE NO. 27.

Is situated in Pueblo county, Colorado, on the St. Charles river just behind the "Hogbacks," at the base of the Greenhorn mountains.

Drainage area about 65 square miles, all on heavy mountain slopes, well wooded, and supplied with streams of continuous flow.

Altitude, 6,300 feet.

Area of reservoir site, 200 acres.

Approximate capacity, 2,340 acre-feet.

RESERVOIR SITE NO. 28.

Is situated in Pueblo county, Colorado, on Graneros creek, a mile above junction with Greeehorn creek, and on high, broken plains near the foothills.

Drainage area of the Graneros is small, and furnishes an insignificant supply; Greenhorn creek can be easily diverted into the basin, and will furnish a mean annual flow of perhaps 20 second-feet. Its drainage area is about 50 square miles, chiefly on the east front of Greenhorn mountain. Slopes heavily timbered. The Huerfano river on the south may be diverted in part by an easily constructed canal 15 miles long.

Altitude, 5,892 feet.

Area of reservoir site, 760 acres.

Approximate capacity, 27,200 acre-feet.

RESERVOIR SITE NO. 29.

Situated in Huerfano county, Colorado, on the Huerfano river, at a narrow gateway in the foothills where the river passes from a broad mountain valley to the plains.

Drainage area about 500 square miles, extending to high mountain crests around half its circumference of about 100 miles. Heavy timber on the higher mountain slopes and light wood on the foothills. The central portion of the basin is a mountain park, clear of timber. Streams have continuous flow and considerable volume.

Altitude, 6,895 feet.

Area of reservoir site, 115 acres.

Approximate capacity, 1,960 acre-feet.

RESERVOIR SITE NO. 30.

Is situated in Huerfano county, Colorado, on Cucharas river, in the foothills between the Spanish peaks and the Culebra range.

Drainage area about 40 square miles, extending 6 or 8 miles back to the summits of the Culebra range and the Spanish peaks. Timber on the higher slopes, and light wood generally distributed. Streams have continuous flow.

Altitude, 7,800 feet.

Area of reservoir site, 130 acres.

Approximate capacity, 4,125 acre-feet.

RESERVOIR SITE NO. 31.

Is situated in Huerfano county, Colorado, on Arapahoe creek, in foothills north of the Spanish peaks.

Drainage area about 25 square miles, heading in the Spanish peaks. A small amount of timber. Light, continuous flow of streams.

Altitude, 7,200 feet.

Area of reservoir site, 4,500 acres.

Approximate capacity, 13,300 acre-feet.

RESERVOIR SITE NO. 32.

Is situated in Huerfano county, Colorado, on Santa Clara river, in the high mesas between the Spanish peaks and the plains.

Drainage area of about 45 square miles, heading on the Spanish peaks. Little timber, and light and continuous flow to streams.

Altitude, 6,700 feet.

Area of reservoir site, 420 acres.

Approximate capacity, 10,150 acre-feet.

RESERVOIR SITE NO. 33.

Is situated in Las Animas county, Colorado, on the Apishapa river, at the eastern edge of Park plateau.

Drainage area of about 100 square miles extending westward to the southern slope of the Spanish peaks. Little heavy timber, but general distribution of light wood. Continuous flow of streams.

Altitude, 6,850 feet.

Area of reservoir site, 440 acres.

Approximate capacity, 12,790 acre-feet.

RESERVOIR SITE NO. 34.

Is situated in Las Animas county, Colorado, on the Purgatoire river at the junction with South fork.

Drainage area about 320 square miles, extending back to the crest of the Culebra range. The basin includes the Stonewall valley and several other settled areas of small size, but its greater portion is heavily timbered. Streams are numerous and have continuous flow.

Altitude, 6,620 feet.

Area of reservoir site, 450 acres.

Approximate capacity, 6,200 acre-feet.

RESERVOIR SITE NO. 35.

Is situated in Las Animas county, Colorado, in Stonewall valley, at the eastern base of the Culebra range.

Drainage area about 50 square miles, all heavily wooded, with a considerable portion of heavy timber. Streams all have strong continuous flow.

Altitude, 8,300 feet.

Area of reservoir site, 240 acres.

Approximate capacity, 11,200 acre-feet.

RESERVOIR SITE NO. 36.

Is situated in Las Animas county, Colorado, on the Purgatoire river in Stonewall valley, at the eastern base of the Culebra range.

Drainage area about 65 square miles, nearly all heavily wooded. Streams have continuous flow.

Altitude, 8,200 feet.
Area of reservoir site, 760 acres.
Approximate capacity, 22,700 acre feet.

RESERVOIR SITE NO. 37.

Is situated in Las Animas county, Colorado, on the Apishapa river, 40 miles east of the mountains.

Drainage area about 420 square miles from the Spanish peaks eastward. Bare of timber excepting in the extreme western portion. Light continuous flow, usually; in exceptionally dry years, intermittent flow.

Altitude, 5,600 feet.
Area of reservoir site, 250 acres.
Approximate capacity, 3,840 acre-feet.

RESERVOIR SITE NO. 40.

Is situated in Las Animas county, Colorado, on Smith canyon creek, 15 miles south of its junction with the Purgatoire river.

Drainage area of about 220 square miles on high, partly wooded plateaus. Main stream has intermittent flow through site.

Altitude, 4,700 feet.
Area of reservoir site, 1,400 acres.
Approximate capacity, 34,230 acre-feet.

RESERVOIR SITE NO. 41.

Is situated in Bent county, Colorado, on Rule creek, midway of its length.

Drainage area of about 140 square miles. No heavy timber and very little light wood growth. Stream flow intermittent.

Altitude, 4,250 feet.
Area of reservoir site, 1,560 acres.
Approximate capacity, 32,780 acre-feet.

RESERVOIR SITE NO. 42.

Is situated in Bent county, Colorado, on Cottonwood creek, 4 miles above junction with Rule creek.

Drainage area of about 110 square miles, among low mesas. Occasional light tree growth on mesas. Stream has winter and spring flow and annual floods.

Altitude, 4,300 feet.
Area of reservoir site, 1,000 acres.
Approximate capacity, 25,880 acre-feet.

RESERVOIR SITE NO. 43.

Is situated in Las Animas county, Colorado, on Two butte creek, at the point where the mesas end in plains.

Drainage area of about 250 square miles, in a region of low mesas, rising to a maximum elevation of 5,500 feet above sea level. Light pine growth along mesa edges. Intermittent flow on stream branches, but continuous flow through reservoir site.

Altitude, 4,500 feet.
Area of reservoir site, 480 acres.
Approximate capacity, 5,900 acre-feet.

RESERVOIR SITE NO. 44.

Situated in Otero county, Colorado, in a depression on the open plains, about 6 miles east of Rocky ford. Depth increased by low dam.

No drainage area; to be supplied by ditch from the Arkansas river.

Altitude, 4,250 feet.

Area of reservoir site, 700 acres.

Approximate capacity, 14,720 acre-feet.

RESERVOIR SITE No. 45.

Is situated in Bent and Otero counties, Colorado, in a depression on the open plains, about 3 miles west of Adobe creek and north of Horse creek, and 8 miles south of Kilburn, on the Missouri Pacific railroad.

No drainage area of importance. To be supplied by ditch from the Arkansas river.

Altitude, 4,150 feet.

Area of reservoir site, 1,680 acres.

Approximate capacity, 21,407 acre-feet.

RESERVOIR SITE No. 46.

Is situated in Kiowa and Bent counties, in a depression on the plains just east of Adobe creek, and 10 miles southeast from Arlington on the Missouri Pacific railroad.

No drainage area of importance. To be supplied by ditch from the Arkansas river.

Altitude, 4,150 feet.

Area of reservoir site, 4,160 acres.

Approximate capacity, 73,300 acre-feet.

RESERVOIR SITE No. 47.

Is situated in Lake county, Colorado, on the Northwest branch of the Tennessee fork of the Arkansas river.

Drainage area about 20 square miles, on the east slope of the main range. Heavily timbered. Streams have continuous flow.

Altitude, 10,600 feet.

Area of reservoir site, 420 acres.

Approximate capacity, 9,600 acre-feet.

RESERVOIR SITE No. 48.

Situated in Lake county, Colorado, on the East fork of the Arkansas river, near the junction.

Drainage area of about 30 square miles; cleared of timber; continuous flow of streams.

Altitude, 10,100 feet.

Area of reservoir site, 250 acres.

Approximate capacity, 4,100 acre feet.

RESERVOIR SITE No. 49.

Is situated in Chaffee county, Colorado, on Pine creek, 5 miles west of the Arkansas river.

Drainage area about 20 square miles; partly wooded; stream has continuous flow.

Altitude, 8,545 feet.

Area of reservoir site, 130 acres.

Approximate capacity, 2,500 acre-feet.

RESERVOIR SITE No. 50.

Is situated in Chaffee county, Colorado, on Pine creek, about 3 miles above its junction with the Arkansas river.

Drainage area about 25 square miles; partly wooded; stream has continuous flow.

Altitude, 8,600 feet.

Area of reservoir site, 90 acres.

Approximate capacity, 1,500 acre-feet.

RESERVOIR SITE NO. 51.

Is situated in Chaffee county, Colorado, on the Arkansas river, at junction with Seven mile creek.

Drainage area of about 600 square miles, extending back to mountain crests on the east and west; heavily timbered on the western mountain slopes; lightly timbered on the eastern slopes, and bare in the valley; continuous flow of all streams.

Altitude, 8,000 feet.

Area of reservoir site, 520 acres.

Approximate capacity, 11,940 acre-feet.

RESERVOIR SITE NO. 52.

Is situated in Fremont county, Colorado, on Oak grove creek, half a mile south of Cotopaxi, and three-fourths of a mile above the junction of Oak grove creek with the Arkansas river.

Drainage area of about 30 square miles on the foothill slopes of the west mountain range. Slopes lightly wooded. Oak grove creek has a light continuous flow.

Altitude, 6,425 feet.

Area of reservoir site, 80 acres.

Approximate capacity, 1,310 acre-feet.

RESERVOIR SITE NO. 53.

Is situated in Pueblo county, Colorado, on Rock creek, 8 miles above its junction with the Arkansas river.

Drainage area of about 30 square miles, running back to low foothills. Not wooded. Usually dry, but subject to annual floods.

Altitude, 5,200 feet.

Area of reservoir site, 300 acres.

Approximate capacity, 6,600 acre-feet.

RESERVOIR SITE NO. 54.

Is situated in Otero and Las Animas counties, Colorado, on Timpas creek, near its head.

Drainage area of about 75 square miles, among low, lightly wooded mesas. Creek has intermittent flow.

Altitude, 4,950 feet.

Area of reservoir site, 840 acres.

Approximate capacity, 13,640 acre-feet.

RESERVOIR SITE NO. 55.

Is situated in Las Animas county, Colorado, on the Las Animas river, at its junction with the Chaquaqua.

Drainage area of about 2,400 square miles, extending westward to the Culebra range and southward to the Raton and Chicorica mesas and Mesa de Maya. Along eastern slope of the Culebra range there is a large slope well timbered; eastward to Trinidad are scattering trees. Eastward of Trinidad trees line the mesa slope occasionally. The Purgatoire and Chaquaqua have a continuous flow.

Altitude, 4,450 feet.

Area of reservoir site, 3,360 acres.

Approximate capacity, 43,330 acre-feet.

DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY.

REPORT

UPON THE

LOCATION AND SURVEY OF RESERVOIR SITES

DURING THE

FISCAL YEAR ENDING JUNE 30, 1892.

BY

A. H. THOMPSON.

CONTENTS.

Page.
Introduction 451
Utah-Idaho 452
    Reservoir site No. 1, Bear lake 452
Utah 458
    Reservoir site No. 2, Silver lake, Salt lake county 458
    Reservoir site No. 3, Twin lakes, Salt lake county 460
    Reservoir site No. 4, Mary's lake, Salt lake county 460
    Reservoir site No. 5, on Sevier river, Millard county 461
    Reservoir site No. 6, on Sanpitch river, Sanpete county 463
    Reservoir site No. 7, on Sevier river, Piute county 465
    Reservoir site No. 8, on East fork of Sevier river, Piute county 466
    Reservoir site No. 9, on Otter creek, Piute county 468
    Reservoir site No. 10, on East fork of Sevier river, Garfield county 470
    Reservoir site No. 11, on East fork of Sevier river, Garfield county 473
    Reservoir site No. 12, Panquitch lake, Iron county 475
    Reservoir site No. 13, at Blue spring, Iron county 475

ILLUSTRATIONS.

		Page.
PL. CLXXXIII.	Reservoir site No. 1, Bear lake, Utah-Idaho	452
CLXXXIV.	Reservoir site No. 6, on San Pitch river, San Pete county, Utah	462
FIG. 150.	Reservoir site No. 2, Silver lake, Salt lake county, Utah	459
151.	Reservoir site No. 3, Twin lakes, Salt lake county, Utah	460
152.	Reservoir site No. 4, Mary's lake, Salt lake county, Utah	461
153.	Reservoir site No. 5, on Sevier river, Millard county, Utah	462
154.	Reservoir site No. 7, on Sevier river, Piute county, Utah	466
155.	Reservoir site No. 8, on East fork of Sevier river, Piute county, Utah	467
156.	Reservoir site No. 9, on Otter creek, Piute county, Utah	470
157.	Reservoir site No. 10, on East fork of Sevier river, Garfield county, Utah	471
158.	Reservoir site No. 11, on East fork of Sevier river, Garfield county, Utah	474
159.	Reservoir site No. 12, Panquitch lake, Iron county, Utah	475
160.	Reservoir site No. 13, at Blue spring, Iron county, Utah	477

THE LOCATION AND SURVEY OF RESERVOIR SITES.

By A. H. Thompson.

INTRODUCTION.

Thirteen reservoir sites, numbered from 1 to 13, inclusive, were surveyed by the Division of Topography during the fiscal year ending June 30, 1892.

Number 1 of these sites, that of Bear lake, is situated partly in Utah and partly in Idaho. The others are entirely in Utah.

These reservoir sites were recommended for reservation from sale or settlement in July and August, 1889, in conformity to act of Congress making appropriations for sundry civil expenses of the Government, approved October 2, 1888, and the act of August 30, 1890, making appropriations for the same purpose, but it was not practicable to commence their definite survey before May, 1891, at which time a party was organized for this purpose and placed under charge of Mr. Morris Bien, Topographer of the U. S. Geological Survey, assisted by Mr. W. B. Corse, Assistant Topographer. Work was prosecuted until the completion of the field surveys in July, 1891.

The final plats of these surveys and schedules of lands segregated, showing in what range, township, section, and subdivision of section of the U. S. Land Survey these sites are situated, were submitted to the Secretary of the Interior, and their final reservation from entry, sale, or settlement, according to law, asked for under date of April 12, 1892.

In the survey of these reservoir sites the topographers were instructed to consider the probable supply of water as indicated by the altitude and area of the drainage basin; the declivity of its slopes, and whether forest-covered, grass-clad, or bare; the rapidity with which water would be delivered into the reservoir; the best location for the dam, taking into account its length, height, availability of proper materials for its construction, and the opportunity for a sufficient spillway; the nearness of cultivable lands and the grade of canal line required to convey the waters to these lands; and, if any choice could be made, they were directed to locate the dams where these requirements were best fulfilled.

In the reports upon the surveys of these reservoir sites the name and situation of each are given, the area and general altitude of its drainage basin; the general character of the topography; the township, range, sections, and subdivisions of each site; the height and location of dam; the bench mark of the survey; the area in acres and approximate content of the reservoir in acre-feet, where material for construction of dam can be found, and the situation of available irrigable lands.

The plats show the situation of the reservoir site in reference to the subdivisions of the U. S. Land Survey, and the approximate location on the same of the line of the water surface at the given height of dam, and they are accompanied by schedules in terms of the General Land Survey to the nearest 40-acre division the areas included, and also by another schedule showing as nearly as can be ascertained, from the records of the General Land Office, whether the lands affected belong to the public domain or to individuals.

The reports, plats, and schedules are designated by corresponding numbers for each reservoir site, a distinct series being used for each state. In addition the figure number of this volume is given for each plat in the report for its site.

UTAH-IDAHO.

Reservoir site No. 1.

(Pl. CLXXXIII.)

Description.

Reservoir site No. 1 is Bear lake, lying half in Rich county, Utah, and half in Bear lake county, Idaho. Its immediate drainage area is about 250 square miles, but the reservoir is to be supplied by a canal about 10 miles long from Bear river.

The area drained by Bear river is 2,400 square miles, lying mostly in Wyoming.

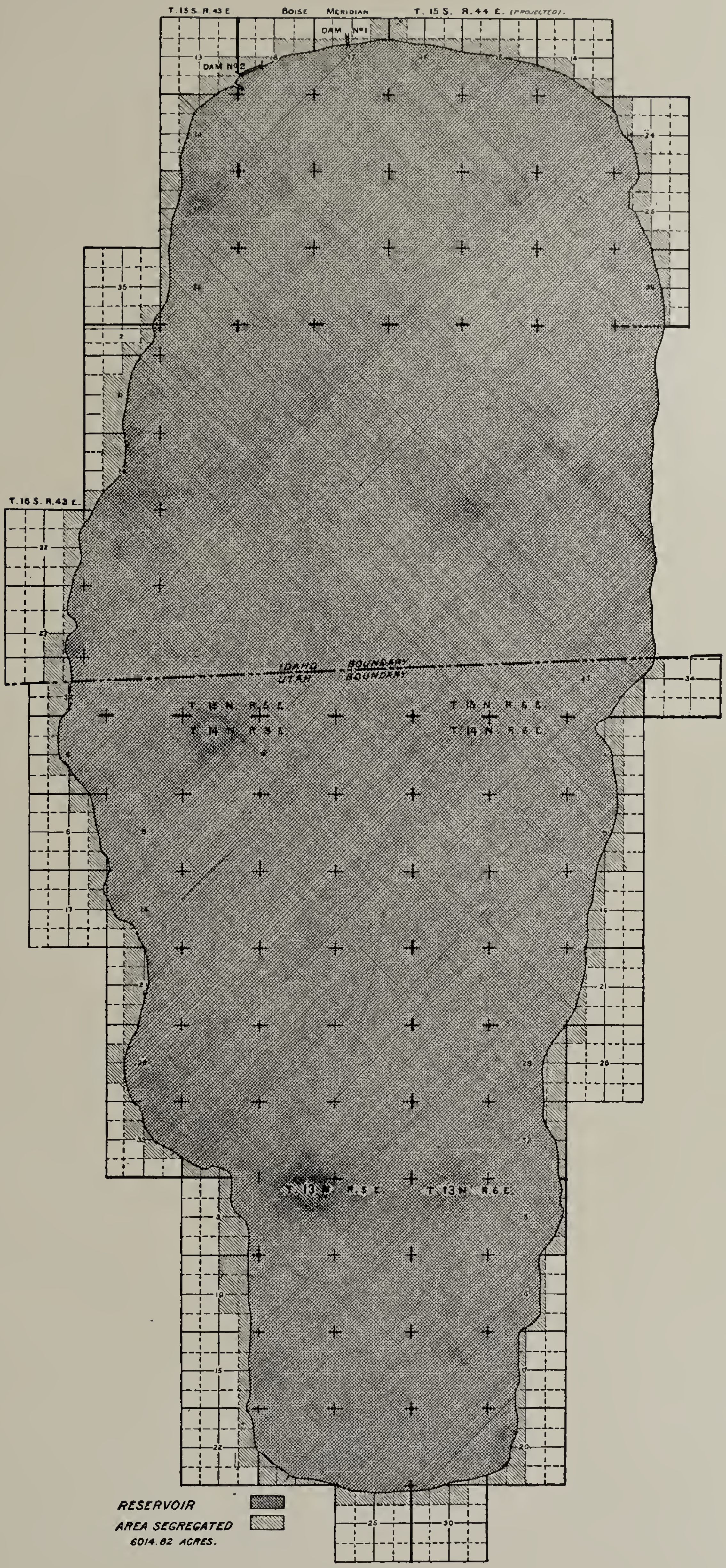
The drainage basin is generally well wooded on the mountain slopes. The altitude of the lake is about 6,000 feet and the mountains run up to 10,000 feet. There are comparatively few stretches of rocky mountain slope.

The reservoir site lies in the following townships and sections in Idaho, Boise meridian: T. 15 S., R. 43 E., Secs. 13, 24, 25, 36. T. 16 S., R. 43 E., Secs. 2, 11, 14, 22, 23, 27.

Projected: T. 15 S., R. 44 E., Secs. 14, 15, 16, 17, 18, 23, 24, 25, 36; T. 16 S., R. 44 E., Secs. 1, 12, 13, 24, 25; and the following in Utah, Salt lake meridian: T. 13 N., R. 5 E., Secs. 3, 10, 15, 22, 23, 24, 25; T. 13 N., R. 6 E., Secs. 5, 8, 17, 19, 20, 30; T. 14 N., R. 5 E., Secs. 5, 8, 9, 16, 17, 21, 28, 33, 34; T. 14 N., R. 6 E., Secs. 4, 9, 16, 21, 28, 29, 32; T. 15 N., R. 5 E., Sec. 32; T. 15 N., R. 6 E., Secs. 33 and 34.

The dam lies near the northeast corner of the S. E. ¼ of the N. E. ¼, Sec. 17, T. 15 S., R. 44 E., Boise meridian, Idaho.

A bench mark was deeply cut on the floor of the road bridge crossing the outlet. The top of the dam is 3 feet above water level and 55 feet long. For 1,800 feet in one place a levee of about 2 feet will be required. The elevation of the lake is 5,946 feet above sea level. The water line was run by a plane table traverse with stadia rod and intersections; the area inclosed by it is 108 square miles—53¾ square miles in Idaho and 54¼ square miles in Utah—and the approximate content is 208,000 acre-feet. It would necessarily be an overflow dam. There is an abundance of rock and timber within 3 miles of the dam and all along the lake shore, except at the northern and southern ends. There are farms along about half the lake shore. The water could be used in the valley of Bear river in Idaho and northern Utah.



RESERVOIR SITE NO. 1, BEAR LAKE, UTAH-IDAHO.

Boise and Salt Lake Meridians.

BEAR LAKE.

Recommended for segregation in letter to the Secretary of the Interior, dated July 29, 1889.

Schedule of lands segregated for reservoir.

IN IDAHO.

[Boise Meridian.]

				Acres.
NE. ¼ SE. ¼	Sec. 13,	T. 15 S.,	R. 43 E	40·00
Lot 1	13	15	43	46·20
E. ½ NW. ¼	24	15	43	80·00
Lot 1	24	15	43	33·20
Lot 2	24	15	43	19·10
Lot 3	24	15	43	42·00
Lot 4	24	15	43	30·90
Lot 1	25	15	43	55·80
Lot 2	25	15	43	43·80
Lot 3	25	15	43	33·20
Lot 4	25	15	43	25·70
Lot 1	35	15	43	38·20
Lot 1	36	15	43	18·20
Lot 2	36	15	43	11·50
Lot 3	36	15	43	7·80
Lot 1	2	16	43	17·50
Lot 2	2	16	43	31·70
Lot 3	2	16	43	21·10
SW. ¼ SE. ¼	2	16	43	40·00
Lot 1	11	16	43	36·65
Lot 2	11	16	43	61·60
Lot 3	11	16	43	54·30
Lot 4	11	16	43	52·80
Lot 1	14	16	43	54·20
Lot 2	14	16	43	52·50
Lot 3	14	16	43	38·20
Lot 4	14	16	43	48·30
NE. ¼ NE. ¼	22	16	43	40·00
Lot 1	22	16	43	37·50
Lot 2	22	16	43	21·70
Lot 3	22	16	43	15·40
Lot 1	23	16	43	21·40
Lot 1	27	16	43	21·20
Lot 2	27	16	43	24·10
Lot 3	27	16	43	50·75
Lot 4	27	16	43	56·80

PROJECTED SURVEY.

S. ½ SE. ¼	Sec. 14,	T. 15 S.,	R. 44 E	61 00
SW. ¼	14	15	44	76·00
SW. ¼ NE. ¼	15	15	44	39·00
S. ½ NW. ¼	15	15	44	34·00
S. ½	15	15	44	13·00
S. ½ NE. ¼	16	15	44	27·00
NW. ¼ NW. ¼	16	15	44	40·00

Schedule of lands segregated for reservoir—Continued.

PROJECTED SURVEY—continued.

				Acres.
S. ½ NW. ¼	Sec. 16,	T. 15 S.,	R. 44 E	4·00
E. ½ NE. ¼	17	15	44	44·00
SW. ¼ NE. ¼	17	15	44	8·00
S. ½ NW. ¼	17	15	44	36·00
S. ½ NE. ¼	18	15	44	64·00
NE. ¼ NE. ¼	23	15	44	11·00
W. ½ NW. ¼	24	15	44	67·00
SW. ¼	24	15	44	87·00
SW. ¼ SE. ¼	25	15	44	40·00
W. ½	25	15	44	125·00
W. ½ NE. ¼	36	15	44	62·00
W. ½ SE. ¼	36	15	44	34·00
W. ½ SW. ¼	1	16	44	26·00
W. ½ NE. ¼	12	16	44	46·00
W. ½ SE. ¼	12	16	44	82·00
W. ½ NE. ¼	13	16	44	76·00
W. ½ SE. ¼	13	16	44	76·00
W. ½	13	16	44	3·00
W. ½ NE. ¼	24	16	44	76·00
W. ½ SE. ¼	24	16	44	75·00
W. ½	24	16	44	5·00
W. ½ NE. ¼	25	16	44	81·00
W. ½ SE. ¼	25	16	44	125·00
W. ½	25	16	44	5·00
Total in Idaho				2,928·30

IN UTAH.

[Salt Lake Meridian.]

				Acres.
Lot 1	Sec. 3,	T. 13 N.,	R. 5 E	17·74
Lot 4	3	13	5	22·02
Lot 5	3	13	5	40·48
Lot 6	3	13	5	41·44
Lot 1	10	13	5	41·31
Lot 2	10	13	5	41·86
Lot 3	10	13	5	46·40
Lot 4	10	13	5	11·60
Lot 1	15	13	5	14·40
Lot 2	15	13	5	15·45
Lot 3	15	13	5	17·37
Lot 4	15	13	5	17·49
Lot 1	22	13	5	20·97
Lot 2	22	13	5	31·76
Lot 3	22	13	5	39·60
Lot 1	23	13	5	17·62
Lot 2	23	13	5	31·20
Lot 3	23	13	5	11·35
Lot 4	23	13	5	5·00
Lot 1	24	13	5	·50
Lot 1	25	13	5	36·42
Lot 2	25	13	5	36·86
Lot 3	25	13	5	37.30

Schedule of lands segregated for reservoir—Continued.

PROJECTED SURVEY—continued.

				Acres.
Lot 4	Sec. 25,	T. 13 N.,	R. 5 E	39·38
Lot 1	5	13	6	8·86
Lot 2	5	13	6	6·82
Lot 3	5	13	6	7·26
Lot 4	5	13	6	28·15
Lot 1	8	13	6	16·59
Lot 2	8	13	6	19·14
Lot 3	8	13	6	26·15
Lot 4	8	13	6	39·05
Lot 5	8	13	6	8·00
Lot 1	17	13	6	18·36
Lot 2	17	13	6	16·83
Lot 3	17	13	6	18·52
Lot 4	17	13	6	17·77
Lot 1	Sec. 19,	T. 13 N.,	R. 6 E	20·72
Lot 2	19	13	6	11·14
Lot 3	19	13	6	3·58
Lot 1	20	13	6	16·46
Lot 2	20	13	6	18·01
Lot 3	20	13	6	34·58
Lot 4	20	13	6	40·24
SE. ¼ SW. ¼	20	13	6	40·00
Lot 1	30	13	6	38·10
NW. ¼ NE. ¼	30	13	6	40·00
NE. ¼ NW. ¼	30	13	6	40·00
Lot 1	5	14	5	27·26
Lot 3	6	14	5	30·41
Lot 4	6	14	5	40·94
Lot 5	6	14	5	31·50
Lot 1	8	14	5	14·55
Lot 2	8	14	5	17·48
Lot 3	8	14	5	24·05
Lot 4	8	14	5	39·60
NW. ¼ NE. ¼	8	14	5	40·00
Lot 1	9	14	5	5·66
Lot 1	16	14	5	2·34
Lot 2	16	14	5	5·72
Lot 3	16	14	5	39·22
Lot 4	16	14	5	26·90
Lot 1	17	14	5	39·90
Lot 2	17	14	5	39·92
Lot 1	21	14	5	40·10
Lot 2	21	14	5	42·10
Lot 3	21	14	5	40·20
Lot 4	21	14	5	24·50
Lot 1	28	14	5	10·00
Lot 2	28	14	5	38·55
Lot 3	28	14	5	36·94
Lot 4	28	14	5	13·17
Lot 1	33	14	5	34·79
Lot 2	33	14	5	39.21
Lot 3	33	14	5	8·62

Schedule of lands segregated for reservoir—Continued.

PROJECTED SURVEY—continued.

				Acres.
Lot 4	Sec. 33,	T. 14 N.,	R. 5 E	37·61
Lot 5	33	14	5	16·51
Lot 1	34	14	5	34·35
Lot 2	34	14	5	28·27
Lot 2	4	14	6	36·05
Lot 3	4	14	6	48·05
Lot 4	4	14	6	39·40
Lot 5	4	14	6	30·75
Lot 1	9	14	6	24·54
Lot 2	9	14	6	25·69
Lot 3	9	14	6	37·73
Lot 4	9	14	6	48·89
Lot 1	16	14	6	18·15
Lot 2	16	14	6	39·91
Lot 3	16	14	6	42·87
Lot 4	16	14	6	46·13
Lot 1	21	14	6	47·69
Lot 2	21	14	6	10·20
Lot 3	21	14	6	20·50
Lot 4	21	14	6	26·58
Lot 1	28	14	6	39·80
Lot 1	29	14	6	9·27
Lot 2	29	14	6	33·90
Lot 3	29	14	6	49·23
Lot 4	29	14	6	49·40
Lot 1	32	14	6	48·45
Lot 2	32	14	6	42·38
Lot 3	32	14	6	28·13
Lot 4	32	14	6	17·90
Lot 1	32	15	5	36·01
Lot 4	32	15	5	32·50
Lot 1	33	15	6	22·25
Lot 2	33	15	6	20·91
SE. ¼ SE. ¼	33	15	6	40·00
Lot 4	34	15	6	33·04
Total in Utah				3,086.52
Total in Idaho				2,928·30
Total area segregated				6,014·82

Action affecting title to lands segregated for Reservoir site No. 1, lying in Idaho in T. 15 S., R. 43 E.; T. 15 S., R. 44 E.; T. 16 S., R. 43 E., and T. 16 S., R. 44 E., Boise meridian, has been taken as follows:

IN IDAHO.

[Boise Meridian.]

					Acres.
NE. ¼ SE. ¼	Sec. 13,	T. 15 S.,	R. 43 E	(preemption, November 14, 1890)	40·00
Lot 1,	13	15	43	(preemption, November 14, 1890)	46·20
E. ½ NW. ¼	24	15	43	(homestead July 9, 1885)	80·00
Lot 1	24	15	43	(preemption, November 20, 1889)	33·20
Lot 2	24	15	43	(preemption, November 20, 1889)	19·10
Lot 3	24	15	43	(homestead, June 25, 1890)	42·00

Schedule of lands segregated for reservoir—Continued.

PROJECTED SURVEY—continued.

					Acres.
Lot 4	Sec. 24,	T. 15 N.,	R. 43 E.	(homestead, June 25, 1890)	30·90
Lot 1	25	15	43	(preemption June 25, 1890)	55·80
Lot 2	25	15	43	(preemption June 25, 1890)	43·80
Lot 3	25	15	43	(preemption June 25, 1890)	33·20
Lot 4	25	15	43	(preemption June 25, 1890)	25·70
SE. ¼ SE. ¼	35	15	43	(homestead April 9, 1886)	40·00
Lot 1	2	16	43	(homestead August 24, 1888)	17·50
Lot 2	2	16	43	(homestead August 24, 1888)	31·70
Lot 3	2	16	43	(homestead August 24, 1888)	21·10
SW. ¼ SE. ¼	2	16	43	(homestead August 24, 1888)	40·00
Lot 1	11	16	43	(homestead August 24, 1888)	36·65
Lot 2	11	16	43	(homestead August 24, 1888)	61·60
Lot 3	11	16	43	(homestead August 24, 1888)	54.30
Lot 4	11	16	43	(homestead August 24, 1888)	52·80
Lot 1	14	16	43	(homestead January 4, 1882)	54·20
Lot 2	14	16	43	(homestead January 4, 1882)	52·50
Lot 3	14	16	43	(homestead January 4, 1882)	38·20
Lot 4	14	16	43	(homestead April 16, 1887)	48·30
NE. ¼ NE. ¼	22	16	43	(homestead July 26, 1886)	40·00
Lot 1	22	16	43	(homestead April 28, 1884)	37.50
Lot 2	22	16	43	(homestead April 28, 1884)	21·70
Lot 3	22	16	43	(homestead April 28, 1884)	15·40
Lot 1	23	16	43	(preemption July 26, 1886)	21.40
Lot 1	27	16	43	(homestead January 12, 1887)	21·20
Lot 2	27	16	43	(homestead January 12, 1887)	24·10
Lot 3	27	16	43	(desert entry May 6, 1889)	50·75
Lot 4	27	16	43	(desert entry May 6, 1889)	56·80
NW. ¼ NW. ¼	24	16	43	(desert entry July 9, 1889)	40·00
SW. NW. ¼	24	16	43	(desert entry August 25, 1882)	40·00
Total in Idaho					1,367·60

Action affecting title to lands segregated for Reservoir site No. 1, lying in T. 13 S., R. 5 E.; T. 13 S., R. 6 E.; T. 14 S., R. 5 E.; T. 14 S., R. 6 E.; T. 15 S., R. 5 E.; and T. 15 S., R. 6 E., Salt lake meridian, has been taken as follows:

					Acres.
Lot 1	Sec. 22,	T. 13 N.,	R. 5 E.	(homestead, December 1, 1883)	20·97
Lot 2	22	13	5	(homestead, December 1, 1883)	31·76
Lot 3	23	13	5	(homestead, September 18, 1888)	11·35
Lot 4	23	13	5	(homestead, September 18, 1888)	5·00
Lot 1	25	13	5	(preemption, January 6, 1872)	26·42
Lot 2	25	13	5	(preemption, January 6, 1872)	36·86
Lot 3	25	13	5	(preemption, January 10, 1876)	37·30
Lot 4	25	13	5	(preemption, January 10, 1876)	39·38
Lot 2	17	13	6	(homestead, December 22, 1890)	16·83
Lot 3	17	13	6	(homestead, December 22, 1890)	18·52
Lot 4	17	13	6	(homestead, December 22, 1890)	17·77
Lot 1	19	13	6	(preemption, July 6, 1872)	20·72
Lot 2	19	13	6	(preemption, July 6, 1872)	11·14
Lot 3	19	13	6	(preemption, July 6, 1872)	3·58
Lot 1	20	13	6	(homestead, December 22, 1889)	16·46
Lot 2	20	13	6	(homestead, December 22, 1889)	18·01
Lot 3	20	13	6	(homestead, December 22, 1889)	34·58

Schedule of lands segregated for reservoir—Continued.

PROJECTED SURVEY—continued.

					Acres.
Lot 4	Sec. 20,	T. 13 N.,	R. 6 E	(homestead, August 21, 1882)	40·24
SE. ¼ SW. ¼	20	13	6	(homestead, December 22, 1890)....	40·00
Lot 1	30	13	6	(preemption, October 28, 1879)	38·10
NE. ¼ NW. ¼	30	13	6	(preemption, October 28, 1879).....	40·00
NW. ¼ NE. ¼	30	13	6	(preemption, January 16, 1872)	40·00
Lot 4	5	14	5	(homestead, January 25, 1882)	40·94
Lot 5	5	14	5	(homestead, January 25, 1882)	31·50
NW. ¼ NE. ¼	8	14	5	(homstead, January 25, 1882).......	40·00
Lot 2	16	14	5	(homestead, September 25, 1884)....	5·72
Lot 3	16	14	5	(homestead, September 25, 1884) ...	39·22
Lot 4	16	14	5	(homestead, September 25, 1884) ...	26·90
Lot 1	17	14	5	(desert entry, January 19, 1889)	39·90
Lot 2	17	14	5	(homestead, September 25, 1884)...	39·92
Lot 1	21	14	5	(homestead, February 24, 1882)	40·10
Lot 2	21	14	5	(homestead, February 24, 1882)	42·10
Lot 3	21	14	5	(homestead, April 19, 1883)..........	40·20
Lot 4	21	14	5	(homestead, April 19, 1883)..........	24·50
Lot 1	28	14	5	(desert entry, October 6, 1882)	10·00
Lot 2	28	14	5	(homestead, December 28, 1889)....	38·55
Lot 3	28	14	5	(homestead, December 28, 1889)....	36·94
Lot 1	33	14	5	(homestead, June 12, 1878)..........	34·79
Lot 2	33	14	5	(homestead, June 12, 1878)..........	39·21
Lot 3	33	14	5	(homestead, June 12, 1878)	8·62
Lot 4	33	14	5	(homestead, June 12, 1878)	37·61
Lot 5	33	14	5	(desert entry, April 6, 1889)	16·51
Lot 1	34	14	5	(desert entry, November 28, 1884)..	34·35
Lot 2	34	14	5	(desert entry, November 28, 1884)..	28·27
Lot 2	4	14	6	(homestead, October 25, 1882)......	36·05
Lot 3	4	14	6	(homestead, September 30, 1881) ...	48·05
Lot 4	4	14	6	(homestead, September 30, 1881)...	39·40
Lot 5	4	14	6	(homestead, September 30, 1881)...	30·75
Lot 2	29	14	6	(homestead, October 20, 1883)......	33·90
Lot 3	29	14	6	(homestead, October 20, 1883)	49·23
Lot 4	29	14	6	(homestead, October 20, 1883)......	49·40
Lot 1	32	14	6	(desert entry, April 19, 1887)	48·45
Lot 2	32	14	6	(desert entry, April 19, 1887)	42·38
Lot 1	32	15	5	(homestead, June 14, 1889)	36·01
Lot 4	32	15	5	(homestead, June 14, 1889)	32·50
Lot 1	33	15	6	(homestead, October 25, 1882)	22·25
Lot 2	33	15	6	(homestead, October 25, 1882)	20·91
SE. ¼ SE. ¼	33	15	6	(homestead, October 25, 1882)	40·00
Total in Utah					1,790·12
Total in Idaho					1,367·60
Total for reservoir site No. 1					3,157·72

UTAH.

RESERVOIR SITE NO. 2.

(Fig. 150.)

Description.

Reservoir site No. 2 is at Silver lake, a small lake at the head of Big Cottonwood creek. This is quite a small reservoir, and its principal value is as a storage reservoir for a possible water supply for Salt lake city. It is 30 miles from the city and 4,400 feet above it. The reservoir lies in Salt lake county, in T. 2 S., R. 3 E., Secs. 34 and 35 projected, Salt lake meridian.

The drainage basin contains about 3 square miles and is about half covered with timber, the rest being bare rocky slopes. The divide bounding the drainage area is about 2,500 feet above the lake—the altitude of the latter being about 8,600 feet.

The dam runs across the middle of the N. ½ NW. ¼ Sec. 35. It would be 52 feet high and 2,700 feet long; but it is only for a short distance that such a height would be required. For 2,000 feet the dam would average only 10 feet in height. The bench mark was cut in the face of a large rock at the west end of the dam where the road turns up the mountain toward Alta.

The water line was run by plane-table traverse with stadia rod and intersections, and incloses an area of 140 acres. The lake has an area of 15 acres. The approximate storage capacity of this reservoir is 2,500 acre-feet.

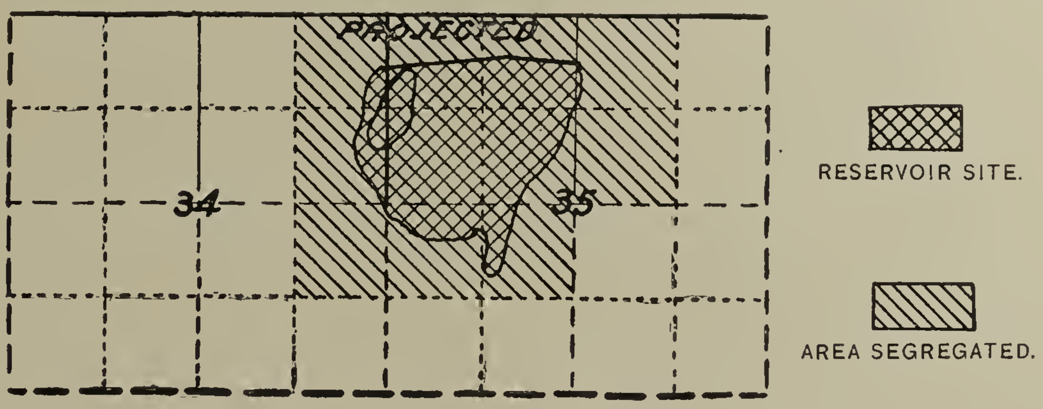


FIG. 150.—Reservoir site No. 2, Silver lake, Salt lake county, Utah.

A spillway could be provided by a short cut in rock at west end of dam; it would be 30 feet long.

There is one ranch covering 160 acres of the area segregated and the houses are within the site. Granite in abundance can be found on the spot. Timber is also abundant.

Salt Lake Meridian.

SILVER LAKE.

Recommended for segregation in letter to the Secretary of the Interior dated August 23, 1889.

Schedule of lands segregated for reservoir.

PROJECTED.

				Acres.
E. ½ NE. ¼	Sec. 34,	T. 2 S.,	R. 3 E.	80
NE. ¼ SE. ¼	34	2	3	40
NW. ¼	35	2	3	160
W. ½ NE. ¼	35	2	3	80
N. ½ SW. ¼	35	2	3	80
Total area segregated				440

Action affecting title to lands segregated for reservoir site No. 2 has been taken as follows:

					Acres.
	Sec. 34,	T. 2 S.,	R. 3 E.	(see mineral entry No. 420).	
W. ½ NW. ¼	35	2	3	(preemption, March, 1875)	80
E. ½ ¼	35	2	3	(preemption, August 24, 1882)	80
Total					160

Reservoir site No. 3.

(Fig. 151.)

Description.

Reservoir site No. 3 is at Twin lakes, at the head of Big Cottonwood creek, in Salt Lake county, lying in T. 2 S., R. 3 E., Sec. 34 projected. This reservoir lies in the same drainage basin with Reservoir site No. 2 and might be used in connection with it for municipal supply. The dam lies at the middle of the east line of NE. ¼ SW. ¼ Sec. 34 where the ridge forming the east rim of the lake basin is cut by its outlet. The dam will be 20 feet high and 180 feet long. The bench mark is cut in a rock at north end of the dam. The lake is about 9,000 feet above sea level. The water line was run with plane table and stadia rod and incloses an area of 25 acres; its content is 450 acre-feet.

A spillway would be cut in the rock at the north end of the dam and would not be over 25 feet long. There is no settlement within the area of the reservoir, and being unsurveyed land, there is no claim upon it. There is, however, a mineral claim located in this section.

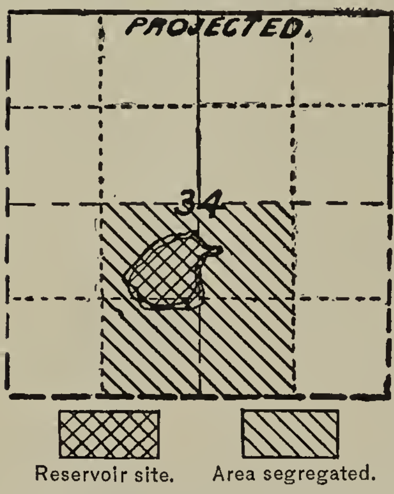


Fig. 151.—Reservoir site No. 3, Twin lakes, Salt lake county, Utah.

This reservoir would be useful in connection with Nos. 2 and 4 for the water supply of Salt lake city.

See the description of drainage area of site No. 2. The immediate drainage area of site No. 3 is three-fourths of a square mile; about two-thirds rocky slope and one-third timbered. There is an abundance of granite and timber on the spot.

Salt Lake Meridian.

TWIN LAKES.

Recommended for segregation in letter to the Secretary of the Interior, dated August 23, 1889.

Schedule of lands segregated for reservoir.

PROJECTED.

	Acres
W. ½ SE. ¼ Sec. 34, T. 2 S., R. 3 E	80
E. ½ SW. ¼ 34, 2 3	80
Total area segregrated	160

Action affecting title to lands segregated for reservoir site No. 3, in T. 2 S., R. 3 E., Salt lake meridian, has been taken as follows:

Sec. 34, T. 2 S., R. 3 E. (See mineral entry No. 420.)

Reservoir site No. 4.

(Fig. 152.)

Description.

Reservoir site No. 4 is at Mary's lake, at the head of Big Cottonwood creek, in Salt lake county, lying in T. 3 S., R. 3 E., Secs. 2 and 3 projected. This reservoir lies in the same drainage basin with reservoir site No. 1 and would be used in connection with it for municipal supply. The dam lies on the section line near the southwest corner of NW. ¼ NW. ¼ Sec. 2, at the point where the outlet cuts through the ridge forming the east rim of the lake basin. The dam is 25 feet high and 140 feet long. The bench mark is cut on solid rock slope at north end of dam. The lake is about 9,000 feet above sea level. The water line of the reservoir was run with plane table, stadia rod, and intersections; it incloses an area of 25 acres and its content is 550 acre-feet. A spillway could be cut in solid rock at south end of dam and would be about 20 feet long.

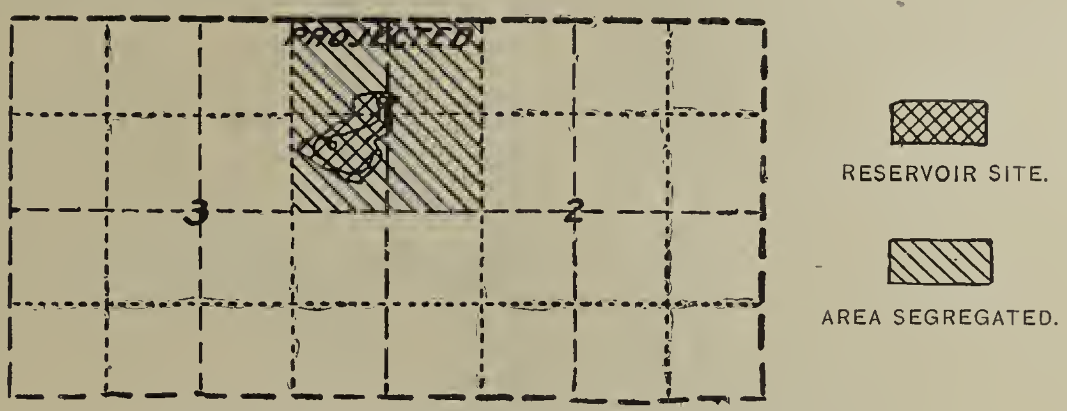


FIG. 152.—Reservoir site No. 4, Mary's lake, Salt lake county, Utah.

This reservoir would be useful in connection with sites 2 and 3 for the water supply of Salt lake city. The immediate drainage basin of the lake covers an area of three-fourths of a square mile and is principally bare rocky slope.

See description of site No. 2.

Granite in abundance at this place and timber also.

Salt Lake Meridian.

MARY'S LAKE.

Recommended for segregation in letter to the Secretary of the Interior, dated August 23, 1889.

Schedule of lands segregated for reservoir.

PROJECTED.

	Acres.
W. ½ NW. ¼ Sec. 2, T. 3 S., R. 3 E	80
E. ½ NE. ¼ 3 3 3	80
Total area segregated	160

Action affecting title to lands segregated for reservoir site No. 4, lying in T. 3 S., R. 3 E., Salt lake meridian, has been taken as follows:

None on record; but there is a mineral claim running down to the lake.

RESERVOIR SITE NO. 5.

(Fig. 153.)

Description.

Reservoir site No. 5 lies on the Sevier river, near Oasis, in Millard county, 40 miles northeast of Sevier lake. The river here is quite large and flows a considerable body of water throughout the year. Its drainage area is over 5,000 square miles. The site lies in T. 16 S., R. 6 W., Secs. 29, 30, 31; T. 16 S., R. 7 W., Secs. 25, 35, 36; T. 17 S., R. 7 W., Secs. 2, 10, 11, 14, 15, Salt lake meridian.

The dam lies in the middle of the NE. ¼ NE. ¼ Sec. 15. It is 16 feet high and

128 feet long and lies at a point where there was a narrow neck of prairie 200 feet wide separating two bends of the river, the river lying in a box canyon 16 feet below the level prairie. This narrow neck has been cut through and the old river bend, about 2 miles long, is now used for a canal. When the reservoir is constructed a dam 475 feet long and 16 feet high will be needed to cut off the old river bend. The first dam is in the cut previously spoken of and piling has been put in for construction. A bench mark was cut on a post standing near the east end of the dam where construction had commenced.

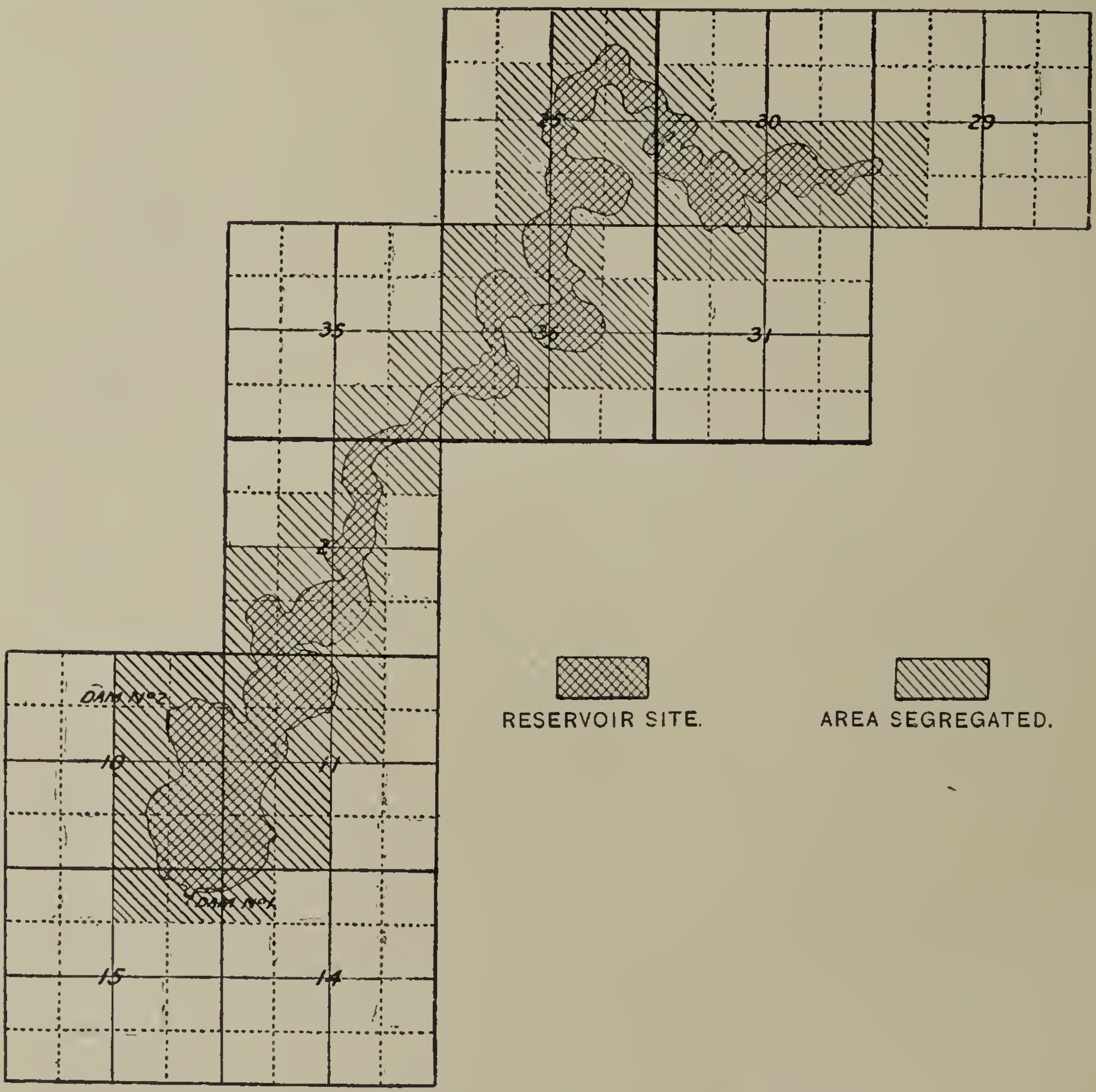
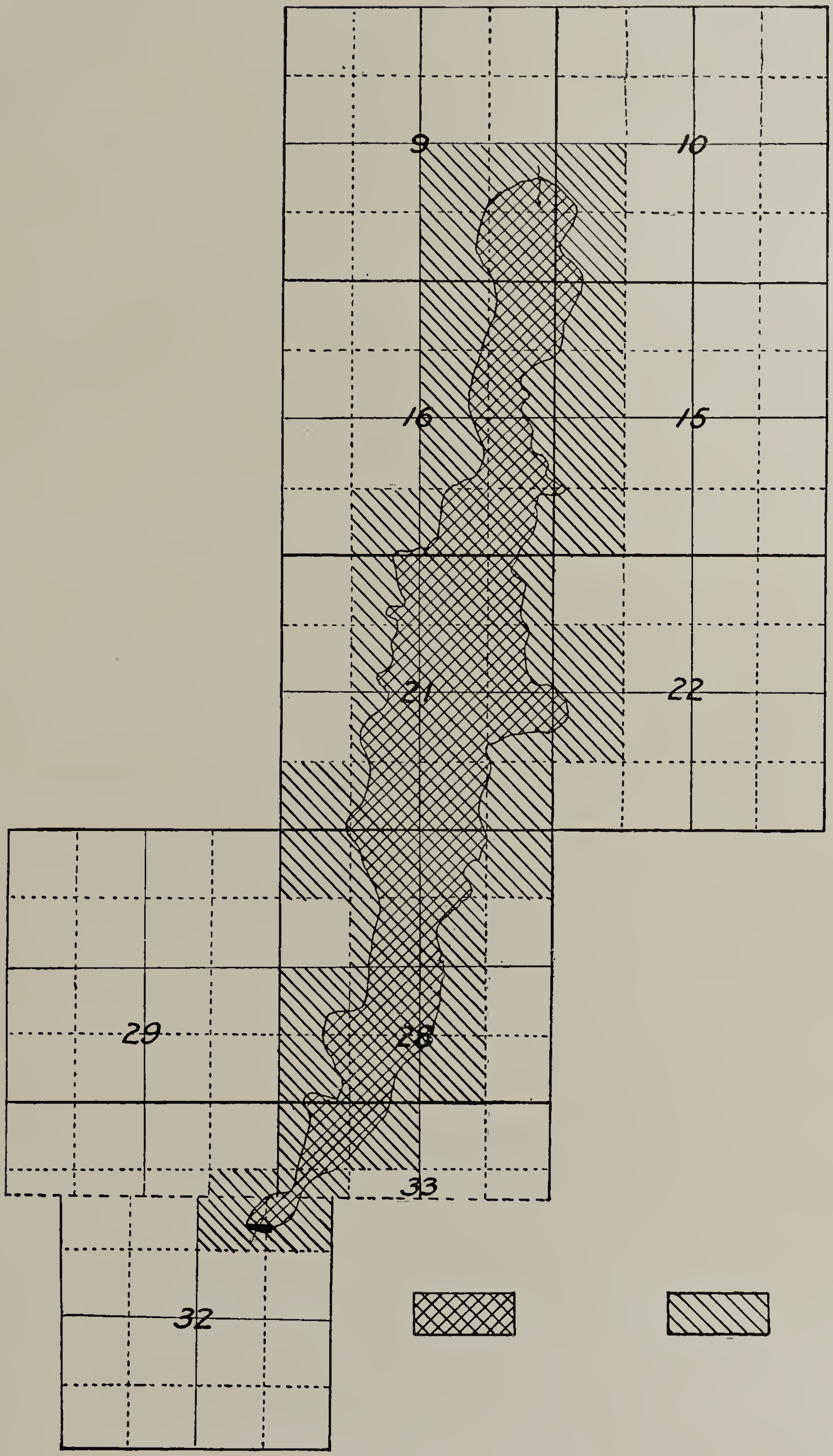


FIG. 153.—Reservoir site No. 5, on Sevier river, Millard county, Utah.

The altitude of the prairie is 4,600 feet. The water line was run with plane table, stadia rod, and intersections, and incloses an area of 940 acres and would contain 10,000 acre-feet of water.

An overflow dam would have to be built, though a spillway might be cut in earth around the end of the dam and would be about 600 feet long. Rock and timber can be found in the mountains 15 miles east. There are no settlements on the reservoir site. The irrigable lands are close at hand, within a mile.



RESERVOIR SITE NO. 6, ON SANPITCH RIVER, SANPETE COUNTY, UTAH.

Salt Lake Meridian.

ON SEVIER RIVER NEAR OASIS.

Recommended for segregation in letter to the Secretary of the Interior, dated August 26, 1889.

Schedule of lands segregated for reservoir.

				Acres.
W. ½ SW. ¼	Sec. 29,	T. 16 S.,	R. 6 W	80·00
Lot 2	30	16	6	50·42
SE. ¼	30	16	6	160·00
SW. ¼	30	16	6	179·28
N. ½ NW. ¼	21	16	6	88·83
NE. ¼	25	16	7	160·00
SE. ¼ NW. ¼	25	16	7	40·00
SE. ¼	25	16	7	160·00
E. ½ SW. ¼	25	16	7	80·00
NE. ¼ SE. ¼	35	16	7	40·00
S. ½ SE. ¼	35	16	7	80·00
SE. ¼ NE. ¼	36	16	7	40·00
W. ½ NE. ¼	36	16	7	80·00
NW. ¼	36	16	7	160·00
N. ½ SE. ¼	36	16	7	80·00
SW. ¼	36	16	7	160·00
N. ½ NE. ¼	2	17	7	79·90
SW. ¼ NE. ¼	2	17	7	40·00
SE. ¼ NW. ¼	2	17	7	40·00
W. ½ SE. ¼	2	17	7	80·00
SW. ¼	2	17	7	160·00
E. ½	10	17	7	320·00
W. ½ NE. ¼	11	17	7	80·00
W. ½	11	17	7	320·00
NW. ¼ NW. ¼	14	17	7	40·00
N. ½ NE. ¼	15	17	7	80·00
Total area segregated				2878·43

Action affecting title to lands segregated for reservoir site No. 5 lying in T. 16 S., R. 6 W.; T. 16 S., R. 7 W., and T. 17 S., R. 7 W., Salt lake meridian, has been taken as follows:

					Acres.
E. ½ SE. ¼	Sec. 10,	T. 17 S.,	R. 7 W.	(homestead, February 20, 1884)	80·00
W. ½ SW. ¼,	11,	17	7	(homestead, February 20, 1884)	80·00
Total					160·00

RESERVOIR SITE NO. 6.

(Pl. CLXXXIV.)

Description.

Reservoir site No. 6 lies on the Sanpitch river in Sanpete county near Gunnison, in T. 18 S., R. 2 E., Secs. 9, 10, 15, 16, 21, 22, 28, 29, 32.

Its drainage area is about 500 square miles and well wooded. The dam lies across the middle of the west line of Lot 1, Sec. 32, just above the mouth of Six mile creek. The dam is 22 feet high and 580 feet long. No bench mark was made, as the greater part of the constructed dam is there. It had been completed, but the middle section was washed out. The altitude is 5,100 feet.

The water line was run with plane table, stadia rod, and intersections; it incloses an area of 830 acres and will contain 9,000 acre-feet. The spillway is over the east end of dam. Stone and timber can be found close to the site. There are no settlements on the reservoir site.

The irrigable lands for this reservoir are 8 miles southwest, at Gunnison.

Salt Lake Meridian.

ON SANPITCH RIVER NEAR GUNNISON.

Recommended for segregation in letter to the Secretary of the Interior, dated July 18, 1889.

Schedule of lands segregated for reservoir.

				Acres.
SE. ¼	Sec. 9,	T. 18 S.,	R. 2 E.	160·00
W. ½ SW. ¼	10	18	2	80·00
W. ½ NW. ¼	15	18	2	80·00
W. ½ SW. ¼	15	18	2	80·00
E. ½	16	18	2	320·00
SE. ¼ SW. ¼	16	18 N., R.	2	40·00
E. ½	21	18	2	320·00
E. ½ NW. ¼	21	18	2	80·00
NE. ¼ SW. ¼	21	18	2	40·00
S. ½ SW. ¼	21	18	2	80·00
SW. ¼ NW. ¼	22	18	2	40·00
NW. ¼ SW. ¼	22	18	2	40·00
N. ½ NE. ¼	28	18	2	80·00
SW. ¼ NE. ¼	28	18	2	40·00
N. ½ NW ¼	28	18	2	80·00
SE. ¼ NW. ¼	28	18	2	40·00
W. ½ SE. ¼	28	18	2	80·00
SW. ¼	28	18	2	160·00
Lot 1	32	18	2	13·79
Lot 7	32	18	2	26·44
Lot 8	32	18	2	26·48
Lot 4	33	18	2	14·03
N. ½ NW. ¼	33	18	2	80·00
Total area segregated				2,000·74

Action affecting title to lands segregated for reservoir site No. 6, lying in T. 18 S., R. 2 E., Salt lake meridian, has been taken as follows:

					Acres.
NE. ¼ SE. ¼	Sec. 9,	T. 18 S.,	R. 2 E.	(homestead, October 1, 1877)	40·00
SE. ¼ SE. ¼	9	18	2	(homestead, May 1, 1878)	40·00
SW. ¼ SE. ¼	9	18	2	(homestead, May 1, 1878)	40·00
NW. ¼ SE. ¼	9	18	2	(homestead, August 6, 1889)	40·00
SW. ¼ SW. ¼	10	18	2	(timber culture, January 30, 1887).	40·00
NW. ¼ SW. ¼	10	18	2	(homestead, June 2, 1880)	40·00
SE. ¼ SW. ¼	16	18	2	(homestead, May 7, 1888)	40·00
NE. ¼	21	18	2	(homestead, January 25, 1877)	160·00
E. ½ NW. ¼	21	18	2	(homestead, May 20, 1882)	80·00
NE. ¼ SW. ¼	21	18	2	(homestead, November 26, 1890)	40·00
SE. ¼ SW. ¼	21	18	2	(homestead, November 26, 1890)	40·00
SW. ¼ NW. ¼	22	18	2	(timber culture, December 8, 1887).	40·00
NW. ¼ SW. ¼	22	18	2	(homestead, April 1, 1884)	40·00
NE. ¼ NE. ¼	28	18	2	(timber culture, July 30, 1887)	40·00

Schedule of lands segregated for reservoir—Continued.

					Acres.
NW. ¼ NE. ¼	Sec. 28,	T. 18 S.,	R. 2 E.	(homestead, August 3, 1883)	40·00
SW. ¼ NE. ¼	28	18	2	(homestead, August 3, 1883)	40·00
NE. ¼ NW. ¼	28	18	2	(homestead, August 3, 1883)	40·00
SE. ¼ NW. ¼	28	18	2	(homestead, August 3, 1883)	40·00
NW. ¼ SE. ¼	28	18	2	(timber culture, July 30, 1887)	40.00
SW. ¼ SE. ¼	28	18	2	(homestead, May 20, 1882)	40·00
SW. ¼	28	18	2	(homestead, December 17, 1884)	160·00
Lot 7	32	18	2	(homestead, May 20, 1882)	26·44
Lot 8	32	18	2	(homestead, May 20, 1882)	26·48
Total					1,172·92

RESERVOIR SITE NO. 7.

(Fig. 154.)

Description.

Reservoir site No. 7 lies on the Sevier river below Marysvale, Piute county; in projected sections—T. 26 S., R. 3 W., Sec. 31; T. 26 S., R. 4 W., Sec. 36; T. 27 S., R. 3 W., Secs. 6 and 7; T. 27 S., R. 4 W., Sec. 1.

The drainage area of the Sevier river is here over 2,500 square miles and fairly well wooded; a considerable part of it is bare rocky slope.

The dam is in the middle of SE. ¼ of NE. ¼ Sec. 36, T. 26 S., R. 4 W., and 2¼ miles below the beginning of the canyon and ¼ mile below the first large creek from the west. It is 10 feet high and 250 feet long. A bench mark was cut in a large rock at east end of dam.

The water line was run with plane table, stadia rod, and intersections; it incloses 290 acres, and will contain 1,600 acre-feet of water.

The altitude here is 5,700 feet. A spillway could be cut in solid rock at the east end of dam and would be 70 feet long.

There is an abundance of rock at the dam site and timber within a mile. The land is unsurveyed and unoccupied. A squatter's claim on the reservoir site has been bought out by a company that intended to construct the dam.

The site is intended to be used as storage for a large canal, irrigating the land around Richfield, Sevier county.

Salt Lake Meridian.

ON SEVIER RIVER NEAR MARYSVALE.

Recommended for segregation in letter to the Secretary of the Interior dated August 26, 1889.

Schedule of lands segregated for reservoir.

PROJECTED.

					Acres.
W. ½ SW. ¼	Sec. 31,	T. 26 S.,	R. 3 W.		80
SE. ¼ NE. ¼	36	26	4		40
NE. ¼ SE. ¼	36	26	4		40
S. ½ SE. ¼	36	26	4		80
S. ½ NE. ¼	6	27	3		80
NW. ¼	6	27	3		160
SE. ¼	6	27	3		160
N. ½ SW. ¼	6	27	3		80
N. ½ NE. ¼	7	27	3		80
SW. ¼ NE. ¼	7	27	3	(This has been surveyed)	40
E. ½ NE. ¼	1	27	4		80
Total area segregated					920

Action affecting title to lands segregated for reservoir site No. 7, lying in T. 26 S., R. 3 W.; T. 26 S., R. 4 W.; T. 27 S., R. 3 W.; and T. 27 S., R. 4 W., Salt lake meridian, has been taken as follows:

	Acres.
SW. ¼ NE. ¼ Sec. 7, T. 27 S., R. 3 W. (desert entry Nov. 3, 1888)	80
Total	80

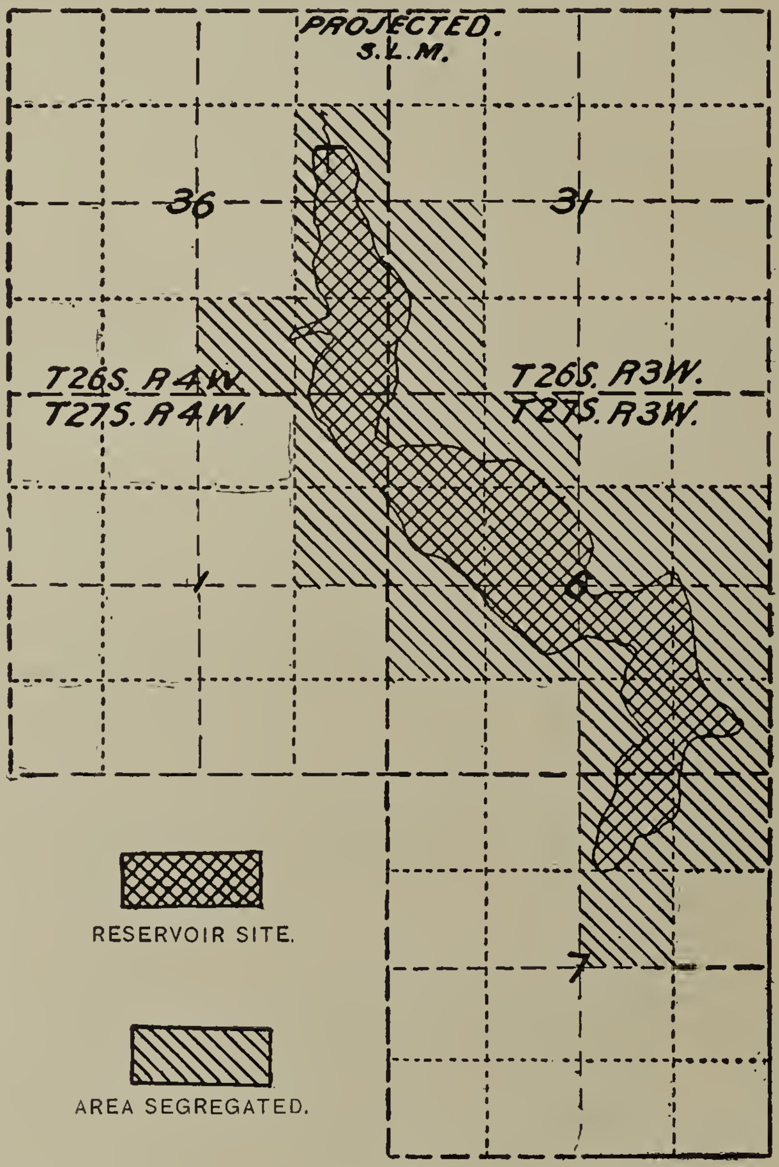


Fig. 154.—Reservoir site No. 7, on Sevier river, Piute county, Utah.

Reservoir Site No. 8.

(Fig. 155.)

Description.

Reservoir site No. 8 is on the east fork of Sevier river, in Piute county. Its drainage basin is 700 square miles, more than half wooded, the rest rocky slopes. The site lies in T. 30 S., R. 2 W., Secs. 29, 30, and projected T. 30 S., R. 3 W., Secs. 24, 25.

The dam lies in the middle of the east half SW. ¼ SE. ¼ Sec. 24, T. 30 S., R. 3 W. It is at the lower end of the upper flat of the lowest canyon of east fork of Sevier river. The dam is 12½ feet high and 280 feet long. A bench mark was cut in solid rock at north end of dam. The altitude is 6,200 feet. The water line was run with plane table, stadia rod, and intersections, inclosing 460 acres, and will contain 3,000 acre-feet of water.

A spillway could be cut in solid rock at north end of dam and would be about 50 feet long.

An abundance of stone can be found at the dam site and timber within a mile. There are three settlers on the site. The water would be used in Circle valley, near Junction city, 8 miles below.

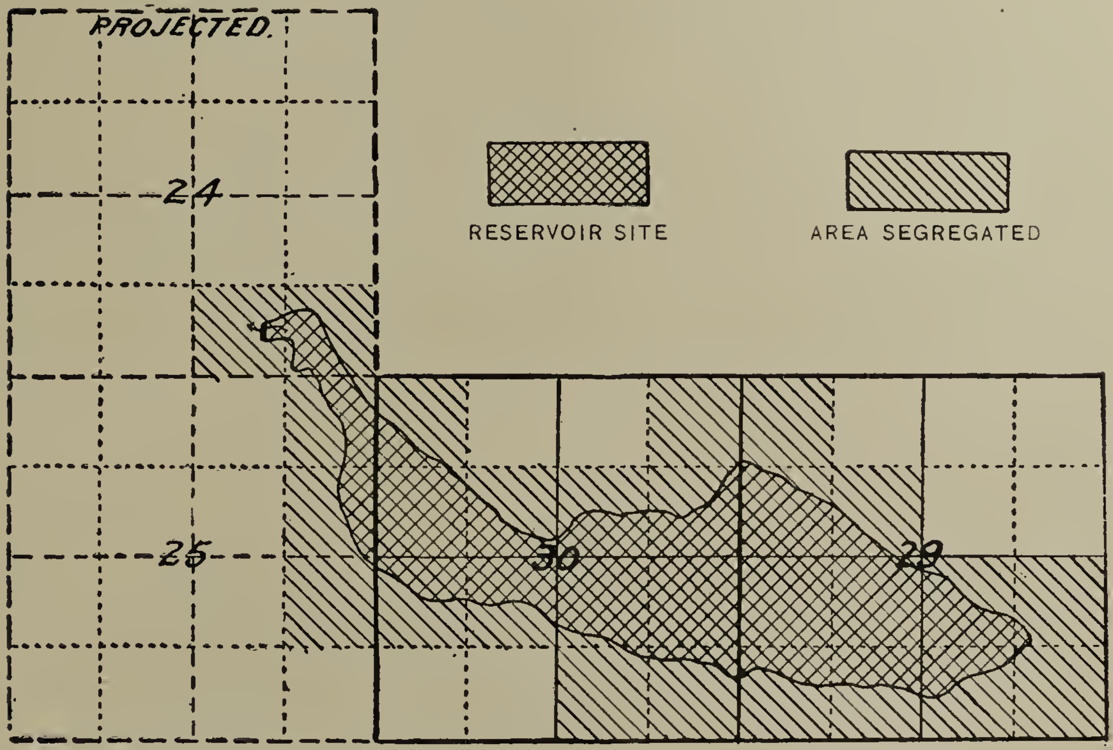


FIG. 155.—Reservoir site No. 8, on east fork of Sevier river, Piute county, Utah.

Salt Lake Meridian.

IN CANYON OF EAST FORK OF SEVIER RIVER.

Recommended for segregation in letter to the Secretary of the Interior, dated August 26, 1889.

Schedule of lands segregated for reservoir.

				Acres.
NW. ¼ NW. ¼	Sec. 29,	T. 30	S., R. 2 W.	40
S. ½ NW. ¼	29	30	2	80
S. ½	29	30	2	320
E. ½ NE. ¼	30	30	2	80
SW. ¼ NW. ¼	30	30	2	40
Lot 1 NE. ¼	30	30	2	40
Lot 2 NE. ¼	30	30	2	40
SE. ¼ NW. ¼	30	30	2	40
SE. ¼	30	30	2	160
N. ½ SW. ¼	30	30	2	80

Schedule of lands segregated for reservoir—Continued.

PROJECTED.

				Acres.
S. ½ SE. ¼	Sec. 24,	T. 30 S.,	R. 3 W.	80
E. ½ NE. ¼	25	30	3	80
NE. ¼ SE. ¼	25	30	3	40
Total area segregated				1,120

Action affecting title to lands segregated for reservoir site No. 8, lying in T. 30 S., R. 2 W.; and T. 30 S., R. 3 W., Salt lake meridian, has been taken as follows:

					Acres.
S. ½ NW. ¼	Sec. 29,	T. 30 S.,	R. 2 W.	(preemption November 14, 1890)	80
NE. ¼ SE. ¼	29	30	2	(preemption December 9, 1890)	40
NW. ¼ SW. ¼	29	30	2	(homestead May 9, 1884)	40
E. ½ NE. ¼	30	30	2	(homestead August 27, 1881)	80
SW. ¼ NE. ¼	30	30	2	(homestead August 27, 1881)	40
SE. ¼ NW. ¼	30	30	2	(homestead February 26, 1881)	40
Lot 1	30	30	2	(homestead February 26, 1881)	40
Lot 2	30	30	2	(homestead February 26, 1881)	40
N. ½ SW. ¼	30	30	2	(homestead December 2, 1885)	80
N. ½ SE. ¼	30	30	2	(homestead May 9, 1882)	80
NE. ¼ SW. ¼	30	30	2	(homestead May 9, 1882)	40
Total					600

RESERVOIR SITE NO. 9

(Fig. 156.)

Description.

Reservoir site No. 9 is on Otter creek, at its mouth in Piute county, lying in T. 30 S., R. 2 W., Secs. 1, 2, 10, 11, 14, 15, 21, 22, 27, and 28.

Its drainage area is about 500 square miles, partly wooded and partly bare rock. The dam lies in the middle of S. W. ¼ N. W. ¼ Sec. 28, at the mouth of Otter creek. A bench mark was cut in solid rock at south end of dam. The dam is 15 feet high and 200 feet long. The altitude is 6,200 feet.

Water line was run with plane table, stadia rod, and intersections. It incloses 1,860 acres, and will contain 14,000 acre-feet of water.

A spillway could be cut in solid rock at south end of dam and would be 25 feet long.

An abundance of rock is on the spot and timber within a mile. There are 5 settlers within the area of the reservoir site.

The water would be used in Circle valley, near Junction city, 10 miles distant.

The dam of this reservoir is close to the upper end of site No. 8.

Salt Lake Meridian.

AT MOUTH OF OTTER CREEK.

Recommended for segregation in letter to the Secretary of the Interior dated August 26, 1889.

Schedule of lands segregated for reservoir.

				Acres.
SW. ¼ NW. ¼	Sec. 1,	T. 30 S.,	R. 2 W.	40·00
NW. ¼ SW. ¼	1	30	2	40·00
S. ½ NE. ¼	2	30	2	80·00
SE. ¼	2	30	2	160·00

Schedule of lands segregated for reservoir—Continued.

				Acres.
S. ½ SW. ¼	Sec. 2	T. 30 S.,	R. 2 W	80·00
E. ½ NE. ¼	10	30	2	80·00
SE. ¼	10	30	2	160·00
N. ½	11	30	2	320·00
NW. ¼ SE. ¼	11	30	2	40·00
SW. ¼	11	30	2	160·00
N. ½ NW. ¼	14	30	2	80·00
SW. ¼ NW. ¼	14	30	2	40·00
NW. ¼ SW. ¼	14	30	2	40·00
E. ½	15	30	2	320·00
E. ½ NW. ¼	15	30	2	80·00
SW. ¼	15	30	2	160·00
E. ½ NE. ¼	21	30	2	80·00
E. ½ SE. ¼	21	30	2	80·00
SW. ¼ SE. ¼	21	30	2	40·00
N. ½ NE. ¼	22	30	2	80·00
SW. ¼ NE. ¼	22	30	2	40·00
W. ½ SE. ¼	22	30	2	80·00
W. ½	22	30	2	320·00
NW. ¼ NE. ¼	27	30	2	40·00
NW. ¼	27	30	2	160·00
W. ½ SW. ¼	27	30	2	80·00
N. ½	28	30	2	320·00
N. ½ SE. ¼	28	30	2	80·00
SE. ¼ SE. ¼	28	30	2	40·00
NE. ¼ SW. ¼	28	30	2	40·00
Total area segregated				3,360·00

Action affecting title to lands segregated for Reservoir site No. 9, lying in T. 30 S., R. 2 W., Salt lake meridian, has been taken as follows:

					Acres.
SW. ¼ NW. ¼	Sec. 1,	T. 30 S.,	R. 2 W	(preemption, December 14, 1878)	40·00
SE. ¼ NE. ¼	2	30	2	(preemption, December 14, 1878)	40·00
SE. ¼	2	30	2	(homestead, March 8, 1884)	160·00
W. ½ NE. ¼	11	30	2	(preemption, June 11, 1881)	80·00
E. ½ NW. ¼	11	30	2	(preemption, June 11, 1881)	80·00
SW. ¼	11	30	2	(homestead, August 14, 1883)	160·00
W. ½ NW. ¼	14	30	2	(homestead, February 18, 1890)	80·00
NE. ¼ NW. ¼	14	30	2	(homestead, February 18, 1890)	40·00
W. ½ SE. ¼	15	30	2	(homestead, September 18, 1882)	80·00
NE. ¼ SE. ¼	15	30	2	(homestead, September 18, 1882)	40·00
SE. ¼ NE. ¼	15	30	2	(homestead, September 18, 1882)	40·00
N. ½ NE. ¼	15	30	2	(preemption, January 20, 1888)	80·00
SW. ¼ NE. ¼	15	30	2	(preemption, January 20, 1888)	40·00
SE. ¼ SW. ¼	15	30	2	(homestead, December 28, 1885)	40·00
SE. ¼ SE. ¼	21	30	2	(homestead, November 18, 1885)	40·00
E. ½ NW. ¼	22	30	2	(homestead, December, 28, 1885)	80·00
SW. ¼ NW. ¼	22	30	2	(homestead, December 28, 1885)	40·00
W. ½ SW. ¼	22	30	2	(homestead, November 18, 1885)	80·00
W. ½ NW. ¼	27	30	2	(preemption, August 28, 1883)	80·00
NE. ¼ NE. ¼	28	30	2	(homestead, November 18, 1885)	40·00
S. ½ NE. ¼	28	30	2	(preemption, August 28, 1883)	80·00

Schedule of lands segregated for reservoir—Continued.

					Acres.
N. ½ SE. ¼	Sec. 28,	T. 30 S.,	R. 2 W.	(homestead, August 29, 1887)	80·00
SE. ¼ SE. ¼	28	30	2	(homestead, August 29, 1887)	40·00
Total					1,560·00

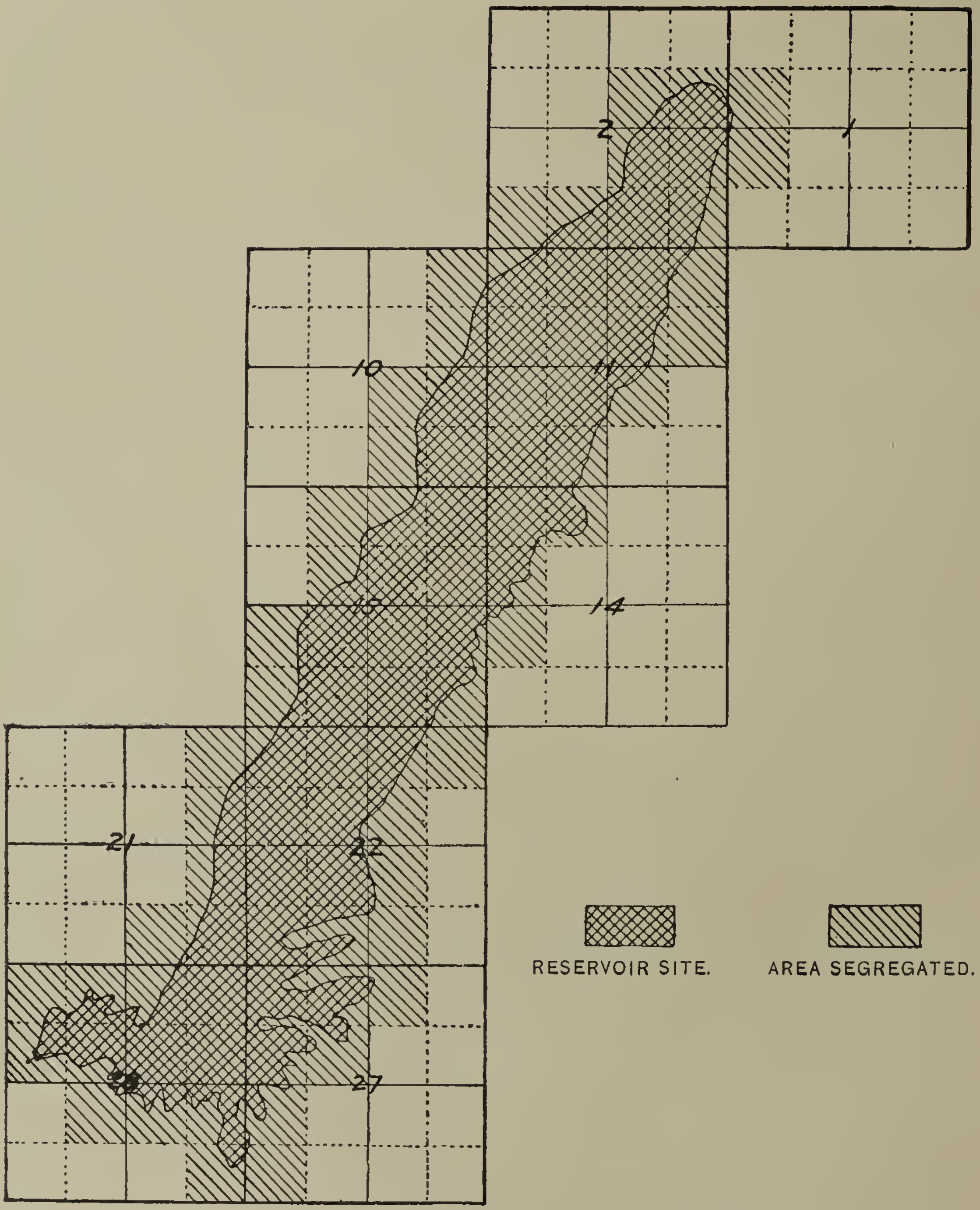


FIG. 156.—Reservoir site No. 9, on Otter creek, Piute county, Utah.

RESERVOIR SITE NO. 10.

(Fig. 157.)

Description.

Reservoir site No. 10 lies on East fork of Sevier river, in Garfield county.

Its drainage area is 575 square miles, about half wooded and half rock slopes. The site lies in T. 32 S., R. 2 W., Secs. 34 and 35; T. 33 S., R. 2. W., Secs. 1, 2, 3, 9, 10, 11, 12, 14, 15, 16, 21, 22, 23.

The dam lies in middle of the west half of S. E. ¼ N. E. ¼, Sec. 2; T. 33 S., R. 2 W., and is 50 feet high and 225 feet long. A bench mark was cut in solid rock at east end of dam a quarter of a mile within the canyon.

The altitude is 7,000 feet.

The water line was run with plane table, stadia rod and intersections; it incloses 3,050 acres and will contain 76,000 acre-feet of water.

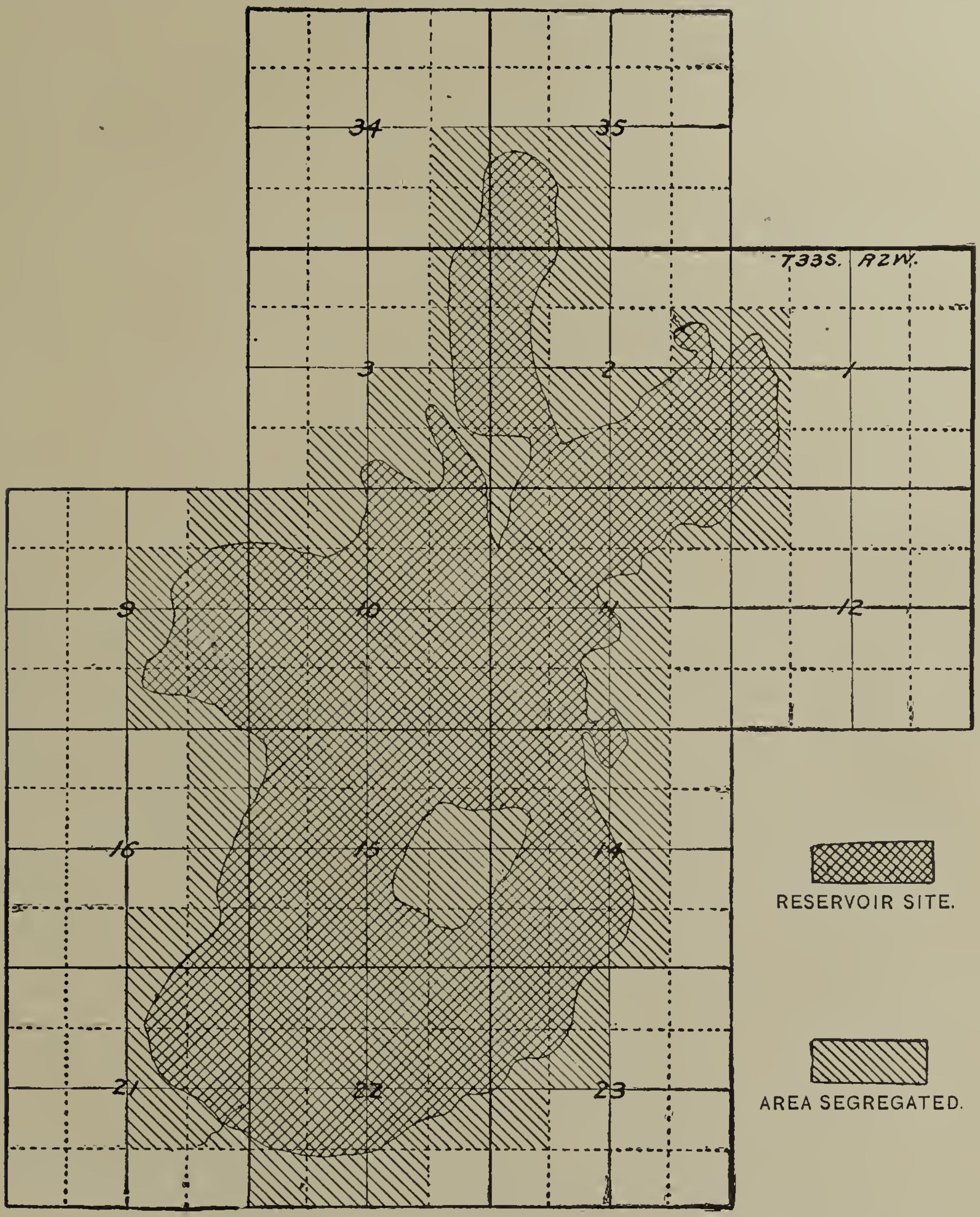


Fig. 157.—Reservoir site No. 10, on east fork of Sevier river, Garfield county, Utah.

It would require an overflow dam.

Rock for construction is abundant at the dam site and there is timber within a mile. There are no houses on the reservoir site. Irrigable land to be served by this reservoir lies 6 miles below.

The flow of the river is not reliable during the dry season, but it is believed that the reservoir could be filled during high water.

Salt Lake Meridian.

LOWER END JOHNS VALLEY, ON EAST FORK SEVIER RIVER.

Recommended for segregation in letter to the Secretary of the Interior, dated August 26, 1889.

Schedule of lands segregated for reservoir.

				Acres.
E. ½ SE. ¼	Sec. 34,	T. 32 S.,	R. 2 W.	80·00
SW. ¼	35	32	2	160·00
SW. ¼ NW. ¼	1	33	2	40·00
W. ½ SW. ¼	1	33	2	80·00
SE. ¼ NE. ¼	[illegible]	33	2	40·00
Lot 3	2	33	2	39·15
Lot 4	2	33	2	38·21
SW. ¼ NW. ¼	2	33	2	40·00
S. ½	2	33	2	320·00
Lot 1	3	33	2	38·81
SE. ¼ NE. ¼	3	33	2	40·00
SE. ¼	3	33	2	160·00
SE. ¼ SW. ¼	3	33	2	40·00
E. ½ NE. ¼	9	33	2	80·00
SW. ¼ NE. ¼	9	33	2	40·00
SE. ¼	9	33	2	160·00
All of	10	33	2	640·00
N. ½ NE. ¼	11	33	2	80·00
SW. ¼ NE. ¼	11	33	2	40·00
W. ½ SE. ¼	11	33	2	80·00
W. ½	11	33	2	320·00
NW. ¼ NW. ¼	12	33	2	40·00
W. ½ NE. ¼	14	33	2	80·00
W. ½ SE. ¼	14	33	2	80·00
W. ½	14	33	2	320·00
All of	15	33	2	640·00
E. ½ NE. ¼	16	33	2	80·00
E. ½ SE. ¼	16	33	2	80·00
SW. ¼ SE. ¼	16	33	2	40·00
NE. ¼	21	33	2	160·00
N. ½ SE. ¼	21	33	2	80·00
NE. ¼	22	33	2	160·00
N. ½ SE. ¼	22	33	2	80·00
SW. ¼ SE. ¼	22	33	2	40·00
W. ½	22	33	2	320·00
NW. ¼	23	33	2	160·00
NW. ¼ SW. ¼	23	33	2	40·00
Total area segregated				4,956·17

Action affecting title to lands segregated for Reservoir site No. 10, lying in T. 32 S., R. 2 W., and T. 33 S., R. 2 W., Salt lake meridian, has been taken as follows:

					Acres.
W. ½ SE. ¼	Sec. 2,	T. 33 S.,	R. 2 W	(timber culture, June 7, 1889)	80·00
SE. ¼ SW. ¼	2	33	2	(timber culture, June 7, 1889)	40·00
E. ½ SE. ¼	10	33	2	(declaratory statement, September 27, 1889)	80·00
SE. ¼ NE. ¼	10	33	2	(declaratory statement, September 27, 1889)	40·00

Schedule of lands segregated for reservoir—Continued.

					Acres.
SW. ¼ SE. ¼	Sec. 10,	T. 33 S.,	R. 2 W	(declaratory statement, September 27, 1889)	40·00
W. ½ NW. ¼	11	33	2	(homestead September 24, 1887)	80·00
W. ½ SW. ¼	11	33	2	(homestead September 24, 1887)	80·00
W. ½ NW. ¼	14	33	2	(desert entry August 25, 1888)	80·00
W. ½ SW. ¼	14	33	2	(desert entry August 25, 1888)	80·00
SW. ¼	15	33	2	(desert entry August 25, 1888)	160·00
S. ½ SE. ¼	15	33	2	(desert entry August 25, 1888)	80·00
NE. ¼ NE. ¼	15	33	2	(desert entry August 25, 1888)	40·00
SE. ¼ NW. ¼	15	33	2	(desert entry August 25, 1888)	40·00
N. ½ NE. ¼	22	33	2	(desert entry June 20, 1891)	80·00
NE. ¼ NW. ¼	22	33	2	(desert entry June 20, 1891)	40·00
S. ½ NE. ¼	22	33	2	(desert entry November 1, 1889)	80·00
NE. ¼ SE. ¼	22	33	2	(desert entry November 1, 1889)	40·00
W. ½ SE. ¼	22	33	2	(desert entry November 1, 1889)	80·00
NW. ¼ NW. ¼	23	33	2	(desert entry June 20, 1891)	40·00
NW. ¼ SW. ¼	23	33	2	(desert entry November 1, 1889)	40·00
Total					1,320·00

RESERVOIR SITE NO. 11.

(Fig. 158.)

Description.

Reservoir site No. 11 lies on the east fork of Sevier river at Flake meadow in Garfield county in T. 35 S., R. 2 W., Secs. 6, 7; T. 35 S., R. 3 W., Secs. 1, 12, 13. Its drainage area is 300 square miles, half wooded and half rocky slopes.

The dams lie near the south line of Sec. 1, in NW. corner of Sec. 12, T. 35 S., R. 3 W., in SW. corner of Sec. 6, and NW. corner of Sec. 7, T. 35 S., R. 2 W., running between two isolated mounds about 50 feet high and joining them to the side slopes of the valley. The dams are 10 feet high and the lengths of the 3 are, respectively, 2,445 feet, 2,240 feet, and 1,640 feet, a total of 6,325 feet. The bench mark is cut in solid rock on east slope of eastern mound. The water line was run with plane table, stadia rod, and intersections. Its altitude is 7,200 feet. The water line incloses an area of 770 acres and will contain 3,500 acre-feet of water.

The spillway would be at south end of eastern dam in earth. Timber and rock are to be found in abundance at the place. There are two houses on the site.

There are irrigable lands immediately adjoining the site.

Salt Lake Meridian.

FLAKE MEADOW ON EAST FORK SEVIER RIVER.

Recommended for segregation in letter to the Secretary of the Interior, dated August 26, 1889.

Schedule of lands segregated for reservoir.

				Acres.
Lot 7	Sec. 6,	T. 35 S.,	R. 2 W	39·43
Lot 1	7	35	2	39·53
Lot 2	7	35	2	39·55
Lot 3	7	35	2	39·57
E. ½ NW. ¼	7	35	2	80·00
S. ½ SE. ¼	1	35	3	80.00
S. ½ SW. ¼	1	35	3	80·00

Schedule of lands segregated for reservoir—Continued.

	Sec.	T.	R.	Acres.
All of	12,	35 S.,	3 W.	640·00
W. ½ NE. ¼	13	35	3	80·00
NW. ¼	13	35	3	160·00
Total area segregated				1,278·08

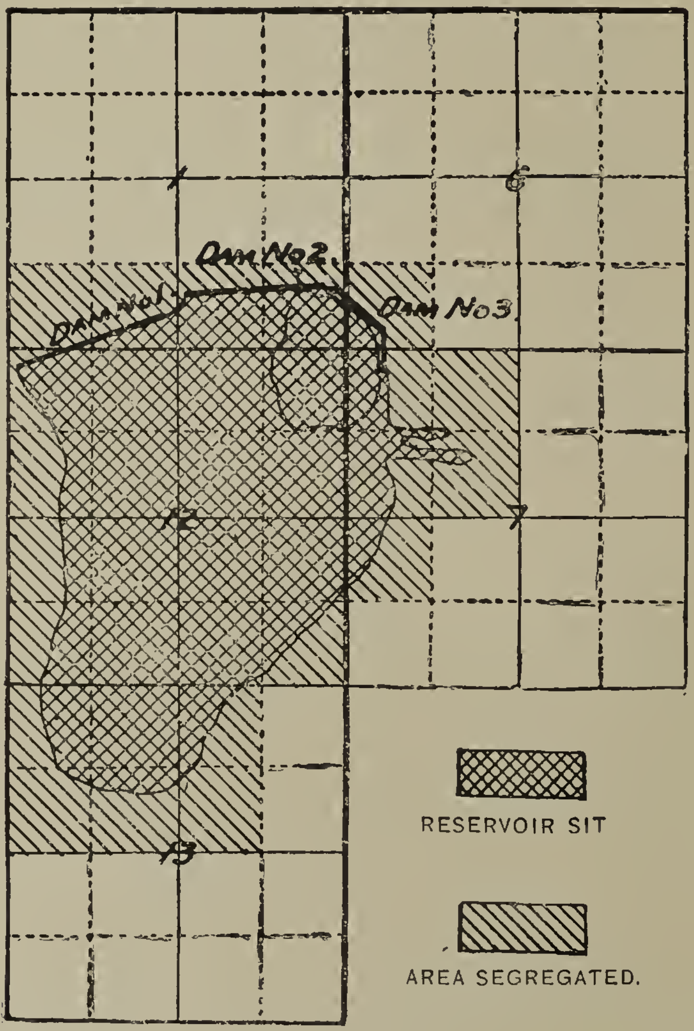


FIG. 158.—Reservoir site No. 11, on east fork of Sevier river, Garfield county, Utah.

Action affecting title to lands segregated for Reservoir site No. 11, lying in T. 35 S., R. 2 W., and T. 35 S., R. 3 W. Salt lake meridian, has been taken as follows:

	¼ Sec.	T.	R.		Acres.
S. ½ SE.	¼ Sec. 1,	T. 35 S.,	R. 3 W	(desert entry, July 30, 1889)	80
N. ½ NE.	¼ 12	35	3	(timber culture, February 7, 1887)	80
SE. ¼ NE.	¼ 12	35	3	(timber culture, February 7, 1887)	40
NE. ¼ SE.	¼ 12	35	3	(timber culture, February 7, 1887)	40
E. ½ SW.	¼ 12	35	3	(desert entry, April 19, 1889)	80
W. ½ SE.	¼ 12	35	3	(desert entry, April 19, 1889)	80
W. ½ NE.	¼ 13	35	3	(desert entry, April 19, 1889)	80
E. ½ NW.	¼ 13	35	3	(desert entry, April 19, 1889)	80
Total					560

RESERVOIR SITE No. 12.

(Fig. 159.)

Description.

Reservoir site No. 12 is at Panquitch lake, Iron county, lying in T. 35 S., R. 7 W., Secs. 32, 33, 34; T. 36 S., R. 7 W., Secs. 3, 4, 5.

Its drainage area is 80 square miles, about one-third wooded and the rest bare slopes, partly rocky.

The dam lies in the middle of the north line of NE. ¼ SW. ¼, Sec. 34, T. 35 S., R. 7 W. Height of dam 10 feet and length 110 feet. A bench mark was cut in solid rock at west end of the dam. The water line was run with plane table and stadia rod and incloses an area of 1,280 acres, of which the present lake occupies 850 acres, and will contain 10,700 acre-feet of water. The altitude is 8,100 feet.

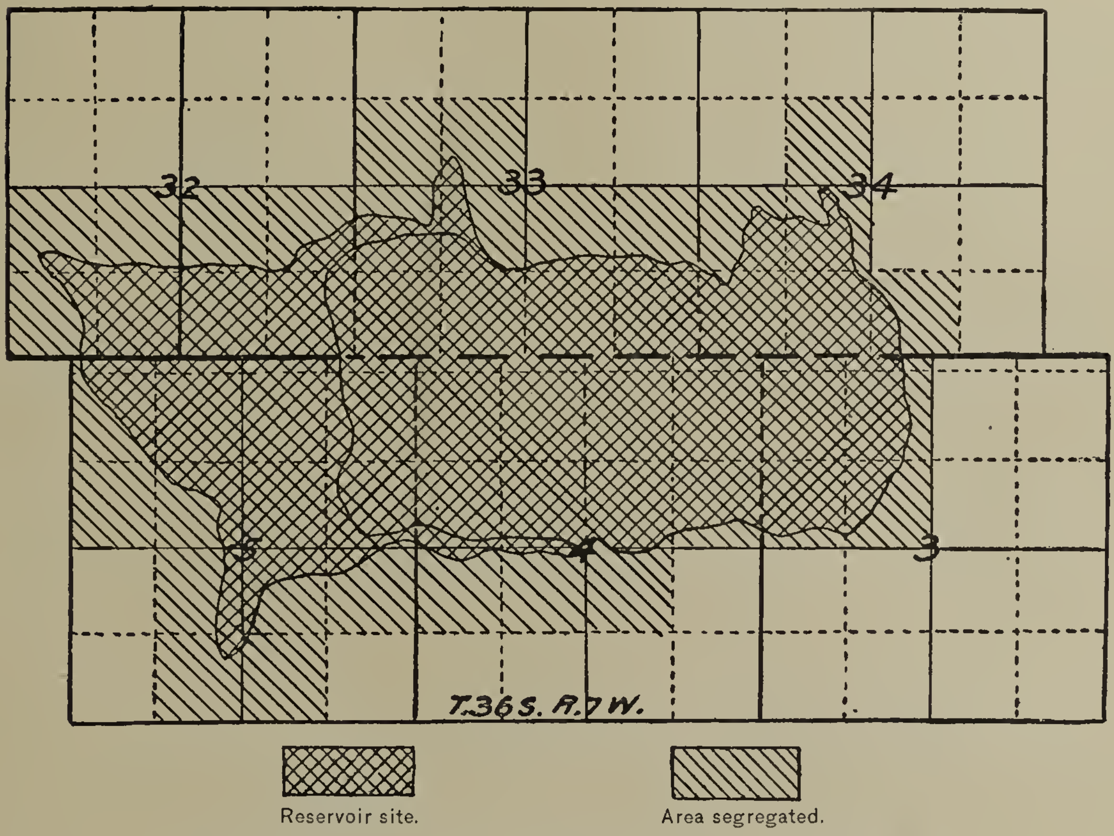


FIG. 159.—Reservoir site No. 12, Panquitch lake, Iron county, Utah.

A spillway could be cut in solid rock at east end of dam and would be 80 feet long.

Rock and timber abound around the lake. There are no houses on the reservoir site, but several cultivated farms would be flooded.

The water would be used on land at the town of Panquitch, 15 miles distant.

The lake has already been raised by an eight-foot overflow dam, and the additional ten-foot dam would doubtless hold all the water the drainage area could supply. Any excess could be retained in Reservoir site No. 13, lying in the same drainage basin.

Salt Lake Meridian.

AT PANQUITCH LAKE.

Recommended for segregation in letter to the Secretary of the Interior, dated August 26, 1889.

Schedule of lands segregated for reservoir.

				Acres.
S. ½	Sec. 32,	T. 35 S.,	R. 7 W.	320·00
S. ½ NW. ¼	33	35	7	80·00
NW. ¼ SE. ¼	33	35	7	40·00
Lot 1	33	35	7	40·70
Lot 2	33	35	7	34·00
Lot 3	33	35	7	5·86
Lot 4	33	35	7	17·30
N. ½ SW. ¼	33	35	7	80·00
SE. ¼ NW. ¼	34	35	7	40·00
Lot 1	34	35	7	25·60
Lot 2	34	35	7	23·60
Lot 3	34	35	7	4·30
Lot 4	34	35	7	38·40
Lot 3	3	36	7	20·25
Lot 4	3	36	7	8·50
Lot 5	3	36	7	31·60
Lot 1	4	36	7	6·61
Lot 2	4	36	7	38·40
Lot 3	4	36	7	13·90
Lot 4	4	36	7	10·20
Lot 5	4	36	7	9·80
NW. ¼ SE. ¼	4	36	7	40·00
N. ½ SW. ¼	4	36	7	80·00
Lot 1	5	36	7	47·38
Lot 2	5	36	7	47·92
Lot 3	5	36	7	47·88
Lot 4	5	36	7	47·82
S. ½ NE. ¼	5	36	7	80·00
S. ½ NW. ¼	5	36	7	80·00
N. ½ SE. ¼	5	36	7	80·00
SW. ¼ SE. ¼	5	36	7	40·00
E. ½ SW. ¼	5	36	7	80·00
Total area segregated				1,560·02

Action affecting title to lands segregated for Reservoir site No. 12, lying in T. 35 S., R. 7 W., and T. 36 S., R. 7 W. Salt lake meridian, has been taken as follows:

					Acres.
S. ½ SE. ¼	Sec. 32,	T. 35 S.,	R. 7 W	(homestead, September 6, 1887)	80·00
S. ½ SW. ¼	32	35	7	(homestead, September 6, 1887)	80·00
SW. ¼ NW. ¼	33	35	7	(homestead, June 17, 1885)	40·00
N. ½ SW. ¼	33	35	7	(homestead, June 17, 1885)	80·00
Lot 2	33	35	7	(homestead, June 17, 1885)	34·00
Lot 3	33	35	7	(homestead, June 17, 1885)	5·86
NE. ¼ SW. ¼	4	36	7	(homestead, January 20, 1887)	40·00
NW. ¼ SE. ¼	5	36	7	(homestead, January 25, 1887)	40·00
S. ½ NE. ¼	5	36	7	(homestead, January 25, 1887)	80·00
Lot 2	5	36	7	(homestead, January 25, 1887)	47·92
NE. ¼ SW. ¼	5	36	7	(homestead, May 21, 1886)	40·00
SE. ¼ NW. ¼	5	36	7	(homestead, May 21, 1886)	40·00
Total					607·78

RESERVOIR SITE No. 13.

(Fig. 160.)

Description.

Reservoir site No. 13 is at the Blue spring, 2 miles S. W. of Panquitch lake, in Iron county, T. 36 S., R. 7 W., Secs. 7, 8, 17, 18.

Its drainage area is 25 square miles, well wooded with few rocky slopes. The dam lies in the middle of Sec. 7, at the upper end of the gorge of the outlet of the valley; it is 48 feet high and 250 feet long. A bench mark was cut in solid rock at the west end.

The water level was run with plane table, stadia rod and intersections; it incloses an area of 440 acres and will contain 13,000 acre-feet of water. Its altitude is 8,200 feet. An overflow dam would be required.

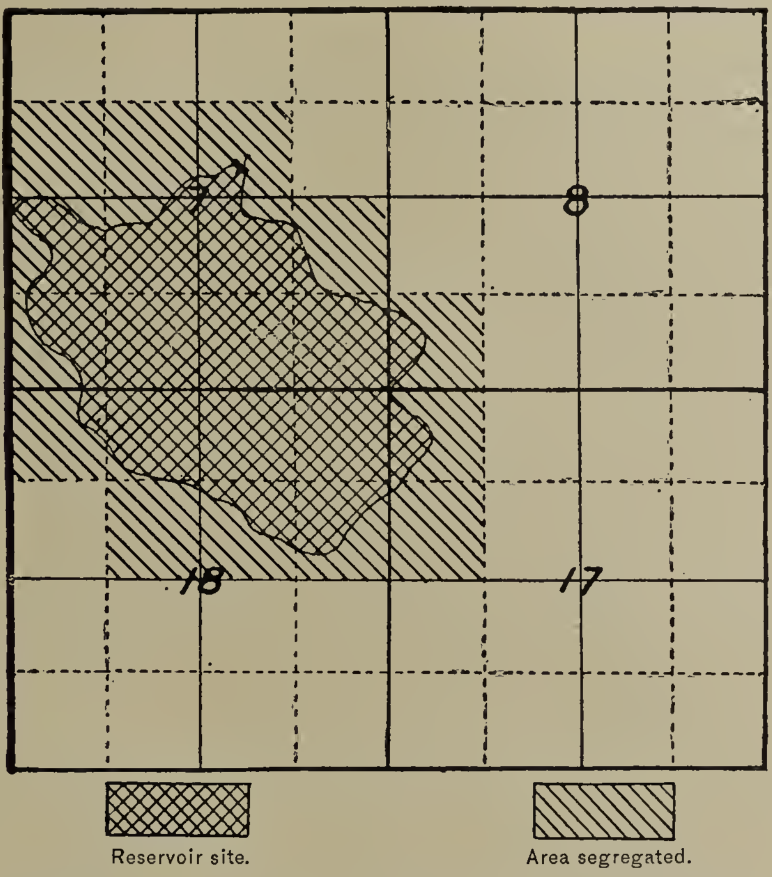


FIG. 160.—Reservoir site No. 13, at Blue spring, Iron county, Utah.

Timber and rock are abundant on the site. There are 2 houses on the site.

This reservoir would be supplementary to No. 12 for the supply of water to lands at Panquitch, 17 miles distant. Its principal supply is a large spring called Blue spring. The flow of this spring might be required in filling Reservoir No. 12, though in some years and possibly every year both No. 12 and No. 13 could be filled.

Salt Lake Meridian.

AT BLUE SPRING.

Recommended for segregation in letter to the Secretary of the Interior, dated August 26, 1889.

Schedule of lands segregated for reservoir.

	Sec.	T.	R.	Acres.
SW. ¼ NE. ¼	7,	36 S.,	7 W.	40·00
SE. ¼ NW. ¼	7	36	7	40·00
Lot 2	7	36	7	40·80
SE. ¼	7	36	7	160·00
E. ½ SW. ¼	7	36	7	80·00
Lot 3	7	36	7	41·20
Lot 4	7	36	7	41·60
SW. ¼ SW. ¼	8	36	7	40·00
W. ½ NW. ¼	17	36	7	80·00
NE. ¼	18	36	7	160·00
E. ½ NW. ¼	18	36	7	80·00
Lot 1	18	36	7	41·79
Total area segregated				845·39

Action affecting title to lands segregated for reservoir site No. 13, lying in T. 36 S., R. 7 W., Salt lake meridian, has been taken as follows:

	Sec.	T.	R.		Acres.
W. ½ S.E. ¼	7,	36 S.,	7 W	(homestead, May 12, 1887)	80·00
Lot 3	7	36	7	(homestead, May 12, 1887)	41·20
Lot 4	7	36	7	(homestead, May 12, 1887)	41·60
E. ½ SW. ¼	7	36	7	(homestead, May 12, 1887)	80·00
N. ½ NE. ¼	18	36	7	(homestead, May 12, 1887)	80·00
E. ½ NW. ¼	18	36	7	(homestead, July 6, 1888)	80·00
S. ½ NE. ¼	18	36	7	(homestead, July 6, 1888)	80·00
Total					482·80

SUMMARY OF AREAS SEGREGATED.

		Acres.
Reservoir site No. 1.	Idaho	2,928·30
	Utah	3,086·52
2.	Utah	440·00
3.	Utah	160·00
4.	Utah	160·00
5.	Utah	2,878·43
6.	Utah	2,000·74
7.	Utah	920·00
8.	Utah	1,120·00
9.	Utah	3,360·00
10.	Utah	4,956·17
11.	Utah	1,278·08
12.	Utah	1,560·02
13.	Utah	845·39
Total area segregated in Utah and Idaho		25,693·65

Being 2,928·30 acres in Idaho and 22,765·35 acres in Utah.

INDEX.

A.

Page.
Alessandro Development Company 309
Alessandro irrigation district 305, 306, 309, 310
Alexander, B. S., cited 155
Alignment of canals 158–161
Alkali 127
Allen, C. P., work of 318
American fork 11, 13, 15, 96, 99, 131
American river 212–213, 232–233
Appropriations, lack of, for engineering work 359
Arapaho canal 302
    composite weir of 230
    culvert on 265
Arizona .33, 95, 115, 124, 137, 150. 153, 156, 162. 175, 336
    precipitation in 27
Arizona canal 175–179, 283
    headworks of 219, 221–224
    regulator of 238, 239, 240–241
    falls on 251, 252
    drainage works of 256, 257
Arkansas, area of 33
Arkansas river ..11, 13, 15, 16, 17, 19, 21, 30, 85, 94, 99 153, 215
    course of 362, 431, 432, 433–435
    utilization of waters of 363
    discharge of 363, 366
    drainage basin of 432, 433
Arkansas river basin, irrigable land in ... 362
    water available in 362, 363
    in Colorado 359, 361, 362–370
    in Colorado, classes of topography in. 362
    mountain ranges of 362
    reservoir sites of 363, 364
    topographic characteristics of 364
    engineering work in 364, 365
    hydrographic basin of 431
    reservoir sites in 436–444
Arrowhead Reservoir Company's reservoirs 317
Artesian wells 113, 326
    development of, for irrigation 326
Artesian wells in western United States . 28–30
Atchison, Topeka and Santa Fé railroad in Texas, relocation of 410, 418–422
Atlas sheet areas 431
Atlas sheets 432–433
Authors cited on irrigation, list 346–349

B.

Bannock creek 425–427
Barton, E. A., cited 159
    works of 203

Page
Bear lake reservoir site 452–458
Bear river 11, 13. 14, 15, 96, 99, 196, 452
Bear river canal 194–198
    crib weir of 226
    regulator of 241
    escapes of 247
    falls on 252
    flumes on 262–264
    culvert on 265–266
Bear valley 400
Bear valley dam 306–322
Bear Valley Irrigation Company's reservoir system 305–310
Bear Valley Land and Water Company .. 306, 309
Bear valley reservoir 305–310, 401
Benchland, between Sun and Teton rivers, area of 373
Benchland reservoir sites 364
Benton lake reservoir 382
Benton lake, water available for storage in 385
Berenda river 187, 188
Berenda-Chowchilla tract 314, 315
Bien, Morris, work of 451
"Big Drop" on Grand river canal 255
Big Laramie river 181, 182
Bighorn river 69, 70
Blackfoot river 423, 424, 425–427
Blake, W. P., work of 297, 298, 301
Blue spring reservoir site 477, 478
Bodfish, Sumner H., work of 364
Boise river 198, 199
Boundary mountains 434
Bowman dam 323, 324
Broad Top coal basin 230
Brown, F. E., work of 306
Brückner, Dr. Edward, work of 25
Buchanan dam 322
Buchanan reservoir system 314–316
Buck scraper, description of 342–344
Buena Vista lake 217

C.

Cache la Poudre river 11, 13, 15, 16, 17, 18, 19, 21, 86, 88, 98, 155, 158
California 32, 95, 96, 109, 114, 115, 121, 123, 124, 125, 126, 128, 132, 136, 138, 139, 143, 146, 150, 159, 160, 162, 168, 191, 203, 210, 327
    precipitation in 27
    drainage basins of 32
    work in 361
    results from surveys of lake basins in. 400

Page.
California, table of annual discharge in reservoir basins of 400
  estimates for dams in 401
California division, work of 398–409
Calloway canal 168, 169, 170
  falls on 251
  open weir of 227–229
  regulator of 239
  distributary head on 271
  distributary ditches on 277
Canal construction, tools and machinery employed in 342–346
Canal plows 342
Canal rollers 342
Canal scrapers 342–344
Canal excavator of San Francisco Bridge Company 345–346
Canal lines, mode of surveying 373
Canals, alignment of 158–161
  perennial 163
  depressed 328
  maintenance and supervision of 281–283
  sources of impairment of 282–283
Carpenter, L. G., cited 125, 274, 335
Carson river 360, 361, 388, 395–397
  lands irrigable from 388
Carson river basin, storage of water in 389
Carson and Truckee valleys 388
Castlewood dam 302–303
Castlewood reservoir 302–304
Central irrigation district canal 191–194
  regulator of 238, 242–243
  culvert on 266–267
Centrifugal pumps 337–338
Cherry creek 302–304
Chowchilla creek 315
Clarks station dam 393–394
Clear lake, survey of 361, 398, 405, 409
Clear lake reservoir 365
Cold creek canyon 389
Cold creek valley reservoir 390, 397
Colorado 32, 76, 78, 84, 86, 87, 88, 89, 90, 93, 94, 109, 114, 115, 121, 123, 124, 126, 139, 140, 143, 149, 153, 156, 159, 161, 163, 327, 328
  bulletin of State Agricultural College, on measurement of water quoted 274
  reservoir sites in 436–444
Colorado divide 362
Colorado Land and Water Company's canal 214
Colorado river 10, 17, 20, 22, 75, 114, 131, 164, 336, 337
Colorado wooden pipes 339
Columbia river 10, 114, 164
Colusa irrigation district 193
Conduits, main 339–340
Connecticut river 12, 17, 18
Corinne branch canal 198
Corse, W. B., work of 451
Cost of water for irrigation 31
Cottonwood lake reservoir 365
Crib weirs 221–227
  at head of Arizona canal 221–224
Crocker-Huffman Land and Water Company 290
Cross section 158–161

Page.
Crystal Springs dam 321–322
Crystal Springs reservoir 319–321
Culebra range 434
Culverts 264–267
  Fresno canal 265
  Arapaho canal 265
  Del Norte canal 265
  Bear river canal 265–266
  Central irrigation district canal 266–267
Cushing, Frank, cited 133
Cuyamaca reservoir 286–290

D.

Dam, diversion, of Idaho Mining and Irrigation company's canal 235–236
  of Pecos canal 236–238
Dams, diversion 234–238
  construction of 321
  rock-filled 323–324
  earth 325
  submerged 327
  at heads of Pecos and Boise canals 325
  in California, estimates for 401
Davidson, George, cited 155
Davidson, Sam., work of 224
Dearborn river 55–57
Delaney gulch dam 325
Del Norte canal 171, 173, 283
  open weir of 229
  regulator of 240
  falls and rapids of 249–250
  culvert on 265
Denver Citizens' Water Company dam 318–319, 325
  cost of 319
Denver Citizens' Water Company, subsurface tunnels of 329
  reservoir 317–319
Denver Water Storage Company's irrigation system 302
  cost of works 304
Depressed canal near Hartland, Kansas 328
Desert land, area of 8
Discharge, mean, tables of 92–99
  annual, in reservoir basins of California, table 400
  of Arkansas river 363, 366
Distributary head, Calloway canal 271
  Idaho canal 271
Distributary pipes 338–340
Distributary systems 268–271
Distribution of water 268–271
Ditch excavators 344–345
Ditch machines 342–346
Donner creek 389
Donner lake glacial basin 389
Donner lake reservoirs 389–391, 397
Dorsey, E. B., cited 157
Drainage 127
Drainage basins 31, 32, 33
Drainage basin of the Arkansas 432, 433
Drainage works 256–258
  Arizona canal 256–257
  Highline canal 257
  Turlock canal 257–258
Dry gulch 425–427

Page.

Dutton, Capt. C. E., work of 7
Duty of water 155–158
Dyas, Col., formula of, for height of crest of fall 250
Dyrenforth, work of 121

E.

Eagle Rock, Idaho 422, 425–427
East Carson river 11, 13, 14, 15, 95, 99
East fork of Sevier river, Garfield county, reservoir site 470–473
  schedule of lands segregated 472, 473
  Piute county, reservoir site 466–468
  schedule of lands segregated 467–468
East Whittier Land and Water Company. 329
Eitel, Fred., work of 194
El Paso dam 410
  site of 415
  design of 415–417
  cost of 417–422
El Paso reservoir 360, 361, 410–422
  land irrigable from 411–412, 414–415
  survey of sites for 412
  area and capacity of 413
  storing of flood waters by 414
  lands to be submerged by 414–415
  upper dam site of 415
  design of dam 415–417
El Paso and Rio Grande railroad 420
Elevators, use of, in water lifting 335
Engineering branch, work of 357–358
Engineering section of irrigation survey, work of 436
Engineering surveys 358
Engineering work, lack of appropriations for 359
  factors to be ascertained before prosecuting 359
  in Arkansas basin 364–365
Escapes 244–256
  of Highline canal 245–246
    Arizona canal 246–247
    Pecos canal 247
    Bear river canal 247
    Turlock canal 247–248
    Idaho canal 248
    Folsom canal 248–249
Evaporation 152–161

F.

Faith valley 396
Falls on Calloway canal 251
    Arizona canal 251–252
    Fresno canals 252
    Bear river canal 252
    Turlock canal 253–255
    Uncompahgre canal 255
Falls and rapids 249–256
  slope of 249
  Del Norte canal 249–250
Falls river 11, 13, 15, 99
Faults, overthrust 228
Firewood west of 100th meridian 8
Fivemile creek 203

Page.

Flake meadow reservoir site 473–474
  schedule of lands segregated 473–474
Flood waters, storing of, in El Paso reservoir 414
Florence Canal Company's works 384
Flumes 258
  on Bear river canal 262–264
Flume on Idaho canal 260–261
    on Highline canal 260
    San Diego 261–262
    Pecos canal 262
Follett, W. W., work of 410–412
Folsom canal, masonry weir of 232–234
  regulators of 243–244
  Folsom dam 321–323
Folsom Water Power Company's canals .. 210–214
  escapes of 248–249
Foote, A. D., work of 199, 422
  cited 200, 203
  device of, for measurement of water .. 273
Fordyce dam 324
Francis formula for measuring water 273
Francisco Garcia grant 414
Fresno canal 165
  falls on 252
  culverts on 265
Fresno scraper 342–344
Friedlander, Isaac, cited 138, 165
Fteley, Alphonse, cited 416

G.

Gallatin river 14, 38, 41, 44, 92
Gannett, Henry, cited 74
Gannett's Dictionary of Altitudes, referred to 432
Gauging stations established 358, 366
Gila river 11, 13, 16, 95, 99, 131, 133
Gilbert, G. K., cited 20
  monograph on Lake Bonneville 20
Glacial basin of Donner lake 389
Grand river canal, "Big Drop," on 255
Graves, Walter H., cited 154, 172
  work of 229
  on measurement of water 272
Gratings on canals in India 250
"Great American Desert" 362
Great lakes 21, 22, 23
Great Salt lake, mean annual height of .. 20, 21, 22
Greeley, A. W., cited 27
Green valley 311
Ground water, volume and movement of. 328
Grunsky, C. E., work of 216

H.

Hagerman canal 188
Hall, W. Ham., cited 125, 192, 194, 312
  work of 314, 389
  work under supervision of 398
Hall, W. L., cited 334, 335
Hayden reservoir 365
Hassayampa river 297
Hayes, C. W., cited 228
Headwork, Arizona canal 219, 221–224
  Turlock and Modesto canals 219

Page.
Headwork, Folsom canal 219
  Pecos and Idaho canals 219
Headworks 218–219
  location of 218
  in Colorado and California 218–219
Heights of crest of falls, formula for 250
Hemet valley reservoir 316–317
  cost of work 317
Henry fork 11, 13, 15, 99
High Sierra reservoirs 398–400
Highline canal 179–181
  crib weir of 224–226
  escapes of 245–246
  drainage works of 257
  flume on 260
Hilgard, E. W., cited 128, 129
Hill, R. T., opinions of 14
History of United States irrigation survey 7
Honda river 187, 188
Honey lake valley 294, 295
Honey Lake Valley Land and Water Storage Company's reservoir system 294–297
Hope valley 396
Hope valley reservoir 395–396, 397
Humbert, C. A., work of 213
Hydrants, measuring 341
Hydrographic basin of the Arkansas 431, 433–435
  topographic survey of 431
  mountain area of 434
  mesa region of 435
  plains region of 435
  reservoir sites in 435–444
Hydrographic survey, work of 357, 358
Hydrography 152–161

I.

Idaho 32, 34, 96, 97, 98, 123, 124, 140, 151, 198, 199, 327
Idaho, rainfall in 27
Idaho canal, flume on 260–261
  distributary heads on 271
Idaho Mining and Irrigating Company's canal 198–203
  diversion dam of 235–236
  escapes of 248
Impairment of canals, sources of 282–283
Independence lake 391, 397
Independence reservoir 391–392, 397
India, irrigation in 116–120, 129
  report on irrigation in, cited 268, 286, 327
  application of water in 327
  Persian wheel of 333, 334
  gratings on canals in 250
  water cushions on canals in 250
Irrigable area in United States 9–10
Irrigable land in Sun river basin, area of 386
Irrigated land, value of 31
Irrigation, area subjected to 8, 9
  cost of, per acre 30
  laws controlling 139–151
  list of works on 346–349
  in India, report on, cited 214, 268, 286
  flumes, wooden, in San Bernardino valley 269
Irrigation survey, plan of operations of 357
Irrigation works, cost of 127

J.

Page.
Jefferson river 38, 49–53
Johnson, Willard D., work of 431
Judith river 60–62

K.

Kansas 32, 122, 124
  artesian wells in 28–30
  depressed canal in 328
Kennedy lake 400, 402
Kennedy lake reservoir 402
Kennedy meadow 400, 401
Kennedy meadows reservoir 401
King river 22, 168, 217
Kern Valley Water Company's canal 216
Kono Tayee, record of precipitation at 407
Kraft Irrigation District canal 184–187
Kraft district canal, crib weir of 226–227

L.

Lake Eleanor 400, 402
Lake Eleanor reservoir 402–403
Lake basins in California, results from surveys of 400
Lake Hemet Water Company's project 316
Lake Tahoe 390, 397
Lake Tenaiya 400, 404
  reservoir 404
  reservoir site 404
Laramie plains, irrigation of 181
Laramie river 79–81, 89
Laws controlling irrigation 139–151
Laybourn flumes 270
Leadville reservoir 365
Lift irrigation 333
Link belt water elevator 335
List of works on irrigation 346–349
Little Bear valley reservoir 317
Little Truckee valley 397
Little Yosemite reservoir 404
Little Yosemite valley 400, 404
Long valley 294, 295
Long valley creek 294–295, 296
Long valley reservoir 394-395, 397
Lower Truckee canals 393–394
Lower Yellowstone river 72–73

M.

Madison river 11, 13, 14, 15, 38, 46–49, 92, 98
Malad river 198
Malheur river 11, 13, 98, 99
Manuel, George E., work of 203
Maintenance of canals 281–283
Marias river 59–60
Marys lake reservoir site 460–461
  schedule of lands segregated 461
Masonry dams 321
Martin, C. D., work of 292
Mathias, Fred, work of 194
Mead, Elwood, cited 140, 158
Measuring hydrant 341
Measurement of water 272–274
  Walter H. Graves quoted on 272
  necessity of a better standard of 272
  unit of 272
  method of in Colorado 273

Page.
Measurement of water, Francis formula for ... 273
  device of A. D. Foote for ... 273
  bulletin of State Agricultural College of Colorado on, quoted ... 274
  L. G. Carpenter on ... 274
Mendel, G. S., cited ... 155
Merced dam ... 325
Merced reservoir supply canal, regulator of ... 239
Merced reservoir system ... 290–294
  cost of ... 294
Merced river ... 290–294, 399
Milk river ... 62–63
Mindeleff, Cosmos. cited ... 133–135
Mississippi river ... 12
Missouri river ... 11, 12, 13, 15, 16, 17, 28, 34–63, 92, 98, 164
Missouri river basin ... 34, 35, 36
Modesto canal, diversion weir of ... 231–232
Modesto irrigation district canal ... 205, 216
Molesworth, Gilford L., cited ... 401
Monongahela river ... 18
Montana ... 32, 34, 70, 92, 93, 123, 124, 126, 140, 164
  rainfall in ... 27, 40, 43–53, 56–63
  drainage basins ... 32, 35, 38
Monte Vista canal, open weir of ... 229–230
Monument reservoir ... 365
Musselshell river ... 60–62

N.

Nebraska ... 32, 82, 91, 122, 124
  rainfall in ... 27
  artesian wells ... 28–30
Nettleton, E. S., cited ... 154, 155, 179, 328
Nevada ... 32, 95, 124, 139, 153, 162, 163
New Croton dam ... 413
Newell, F. H., cited ... 124, 152, 157
New Era excavator ... 345
New Mexico ... 32, 94, 124, 137, 150, 187, 188
  precipitation in ... 27
North Dakota ... 32, 122, 124, 140, 164
  artesian wells in ... 28–30
North Fork of Sun River, gaugings of ... 372
  average discharge of ... 372
North Platte ... 83, 87
North Spring River ... 187, 188

O.

O'Brien's Station dam ... 393, 394
Ogden River ... 11, 13, 15, 96
Ohio River ... 12
Oklahoma ... 122
Old Bear Valley dam ... 306–308
  cost of ... 309
Ontario Colony's water-supply tunnel ... 329
Oregon ... 32, 98, 124, 139
  drainage basins of ... 31
Oregon Short Line railway ... 424, 425
Otter creek reservoir site ... 468–470
  schedule of lands segregated ... 468–470
Owyhee river ... 11, 13, 98

P.

Panquitch lake reservoir site ... 475–476
  schedule of lands segregated ... 476

Page.
Pecos canal, diversion dam of ... 236–238
  regulator of ... 239, 241–242
  escapes of ... 247
  flume on ... 262
Pecos city ... 188
Pecos Irrigation and Improvement Companys canals ... 188–191
Pecos river ... 187–181
Pecos valley canals ... 187–198
Perennial canals ... 163
Periar dam ... 322
Perris irrigation district ... 305, 306, 309, 310
Persian wheel of India ... 333, 334
Phyllis branch of Boise canal, rapids on ... 256
Phyllis canal ... 202
Phyllis branch of Idaho canal, inverted siphon on ... 266
Pipes, cement ... 340–341
  Colorado wooden ... 339
Platte river ... 30, 73–79, 81, 82, 85
Plows employed in constructing works ... 342
Pocatello canal ... 422–427
  estimates of cost of ... 425–427
"Poetch" process ... 410, 417
Portneuf river ... 423, 424, 425–427
Potter, G. W., work of ... 328
Potomac river ... 12, 17, 18
Powder river ... 71–72
Precipitation, variations in ... 25–27
  record of, at Kono Tayee ... 407
Pring reservoir ... 365
Provo river ... 11, 13, 15, 97
Pumping ... 114, 332
Pumping engines ... 336–338
Pumping plants ... 336–338
Pumps, steam, value and utility of, for irrigation ... 336

R.

Ragtown pass, canal over ... 393
Rain, artificial production of ... 121
Rainfall record in Clear lake basin ... 407–408
Rampart range ... 434
Rapids on Grand river canal ... 255–256
  on Phyllis branch of Boise canal ... 256
Reclaimable land in Sun river basin, area of ... 373
  water supply necessary ... 373
  water supply available ... 385
Red Rock river ... 13
Refugio colony grant ... 414–415
Regulator, Central district canal ... 238
  Arizona canal ... 238–239, 240–241
  Calloway canal ... 239
  Pecos canal ... 239
  Merced reservoir supply canal ... 239
  Del Norte canal ... 240
  Bear River canal ... 241
  Idaho canal ... 243
  Folsom canal ... 243–244
Reservoir and canal system of San Diego Flume Company ... 286–290
  cost of ... 290
Reservoir site in Utah-Idaho ... 451, 452–458
Reservoir sites ... 358, 360–361

Page.

- Reservoir sites of Arkansas basin 363–364
  - classes of 363–364
  - surveyed 364–365
  - in hydrographic basin of the Arkansas 435–444
  - in Utah 451, 458–478
- Reservoir system of Honey Lake Valley Land and Water Company 294–297
  - cost of works 296–297
  - of Bear Valley Irrigation Company 305–310
- Reservoirs 284
  - cost of, per acre-foot 284, 285
  - classification of 284–286
- Rio Grande 11, 13, 14, 15, 94, 99, 114, 131, 137, 171, 172
  - sediment carried by 411
  - evaporation and discharge of 411
  - basin, topographic work in 360
- Rivers west of one hundredth meridian 10–34
- Rivers, discharge in second-feet 11
  - relative run-off of 13
  - fluctuations of 15
  - oscillations of 17–25
- Riverside, California, mode of applying water at 279–280
- Robinson, E. N., work of 298
- Rock-filled dams 323–324
- Rockwood, C. R., work of 405
- Rogers, John B., work of 373
- Rollers used in preparing soil 342
- Ross creek 424

S.

- Sacramento river 12, 114, 131, 155, 164, 191–193, 242
- Sacramento valley 191, 212
- Salt river 11, 12, 13, 94, 99, 133, 135, 175
- Salt lake city, water supply of 458–459, 460, 461
- San Bernardino valley 306, 309
  - rainfall in 306
- San Diego canal, flume on 261–262
- San Diego Flume Company, reservoir and canal system of 286–290
- San Diego Land and Townsite Company 310
- San Diego river 286, 287–290
  - diversion weir across 230–231
- San Francisco Spring Valley Water Company reservoir 319–321
- San Francisco Bridge Company, canal excavator of 345–346
- San Joaquin river 17, 20, 22, 131, 155, 168
- San Joaquin valley 398–399, 404
  - water storage in 399–400
  - water supply in 405
- Sanborn, John W., cited 156
- Sangre de Cristo range 362, 434
- Sanpitch river, Sanpete county, reservoir site 463–465
  - schedule of lands segregated 464–465
- Santa Ana river 309
- Savannah river 12, 17
- Sawatch range 362, 434
- Sawtooth mountains 198
- San Fernando Land and Water Company, submerged dam of 331–332
- Schott, C. A., work of 24
- Schuyler, James D., work of 311

Page.

- Schuyler, J. D., cited 157, 277, 281, 312, 316
- Sedimentation 130–132
- Seepage 152–161
- Seven rivers 188
- Sevier river 11, 13, 97, 99
  - Millard county, reservoir site 461–463
  - schedule of lands segregated 463
  - Piute county, reservoir site 465–466
  - schedule of lands segregated 465–466
- Silt 130–132
- Silver lake reservoir site 458–459
  - schedule of lands segregated for 459
- Siphon, inverted, on Phyllis branch of Idaho canal 266
- Siphons, inverted. (*See* Culverts.)
- Slope 158–161
- Smith river 57–59
- Smoky mountains 229
- Snake river 11, 12, 13, 15, 98, 99, 199, 360, 361, 422
- Snelling, California 291, 292
- South Dakota 32, 124
  - artesian wells in 28–30
- South fork of Sun river, discharge of 372
- South Platte 84, 87, 89, 93
- South Spring river 187, 188
- Southern Pacific railroad, in Texas, relocation of 410, 418–422
- Spain, irrigation in 132
- Spanish fork 11, 13, 15, 97, 99
- Specht, George J., cited 343, 349
- Springmeyer valley reservoir 394–395
- Stanislaus river 399
- Stevenson, C. L., cited 157
- Stony creek 184–186, 193
- Storage reservoir on Chowchilla creek 315
- Storage works, object of 284
  - classification of 284
- Streams west of one hundredth meridian 10–34
- Streams, relative run-off 13
- Subconduit under South Platte river 328
- Subirrigation 338
  - application of water to 280–281
- Submerged dam of American Water Company 330–331
  - of San Fernando Land and Water Company 331–332
- Submerged dams 327, 328, 330–332
- Subsurface canals 327–330
- Subsurface water level 326
  - rise of 327
- Subsurface water tunnels 328–329
  - of Denver Citizens' Water Company 329
- Sugar Loaf reservoir 365
- Sun river 11, 13, 15, 55–57, 93, 98, 360, 361
  - area of reclaimable land of 373, 386
  - available water supply in 385
  - reservoir system 371–386
  - region comprised in 371
  - topography of 371
  - rainfall in 371, 372
  - areas of catchment basins of 371
  - available water of 372
  - method of surveying 373
- Sun river system, reservoirs 374–383
  - earth dams of 374

Page.

- Sun River system, area of land irrigable by 386
  - cost of works 386
  - revenue to be derived from 386
- Surveys of lake basins in California, results from 400
- Sweetwater creek 310
- Sweetwater dam 310–312, 322
- Sweetwater reservoir 312, 314
  - distributive system of 313
  - cost of work 313–314
- Sweetwater river 79

T.

- Taylor, L. H., work of 294
- Tennessee park reservoir 365
- Tennessee pass 434
- Teton river 11, 13, 15, 59–60, 97–99
- Texas 94, 124, 187, 188
  - artesian wells of 28, 30
- Thompson, A. H., cited 286
- Timber west of one hundredth meridian 8
- Tongue river 70–71
- Topographic maps 431–433
- Topographic survey of hydrographic basin of the Arkansas 431
- Truckee and Carson river systems 387–389
- Truckee meadows 393, 397
- Truckee reservoir dam 390
- Truckee river 15, 99, 153, 360, 361, 389–394, 397
- Truckee river basin, storage of water in 389
- Tuolumne meadows 400, 403
- Tuolumne meadows reservoir 204, 403
- Tuolumne river 204, 205, 216, 399
- Turlock canal 203–210
  - diversion weir of 231–232
  - water cushions on 250–251
  - falls on 253–255
  - drainage works of 257–258
- Turlock dam 321–323
- Twin lakes 365
  - survey and mapping of 366
- Twin lakes dam 367
  - materials estimated for 367
- Twin lakes reservoir 360, 365
  - catchment area of 366
  - capacity of 366
  - advantages of 366–367
  - mode of discharging water of 368
  - form of conduit of 368–369
  - estimates of quantities required in construction of 369
  - storage capacity of 370
  - annual income on original outlay for 370
- Twin lakes reservoir site 460
  - schedule of lands segregated 460

U.

- Ulrich, J. C., work of 194
- Uncompahgre canal, falls on 255
- "Underflow" 326
- Unit of water measurement 272
- Upper Carson river 387–388
- Upper Salt lake valley 194

Page.

- Upper Truckee system, lands irrigable from 387
- Upper Truckee river, catchment basin of 387
- U. S. Land Survey 451, 452
- Utah 96, 97, 109, 137, 149, 163
  - rainfall in 27
  - drainage basins of 32
  - reservoir sites in 451, 458–478
- Utah and Northern railway 423, 424
- Utah-Idaho reservoir site 451, 452–458
- Utah Lake, mean monthly height of 19, 21

V.

- Van Dyke, T. S., cited 279
  - work of 287

W.

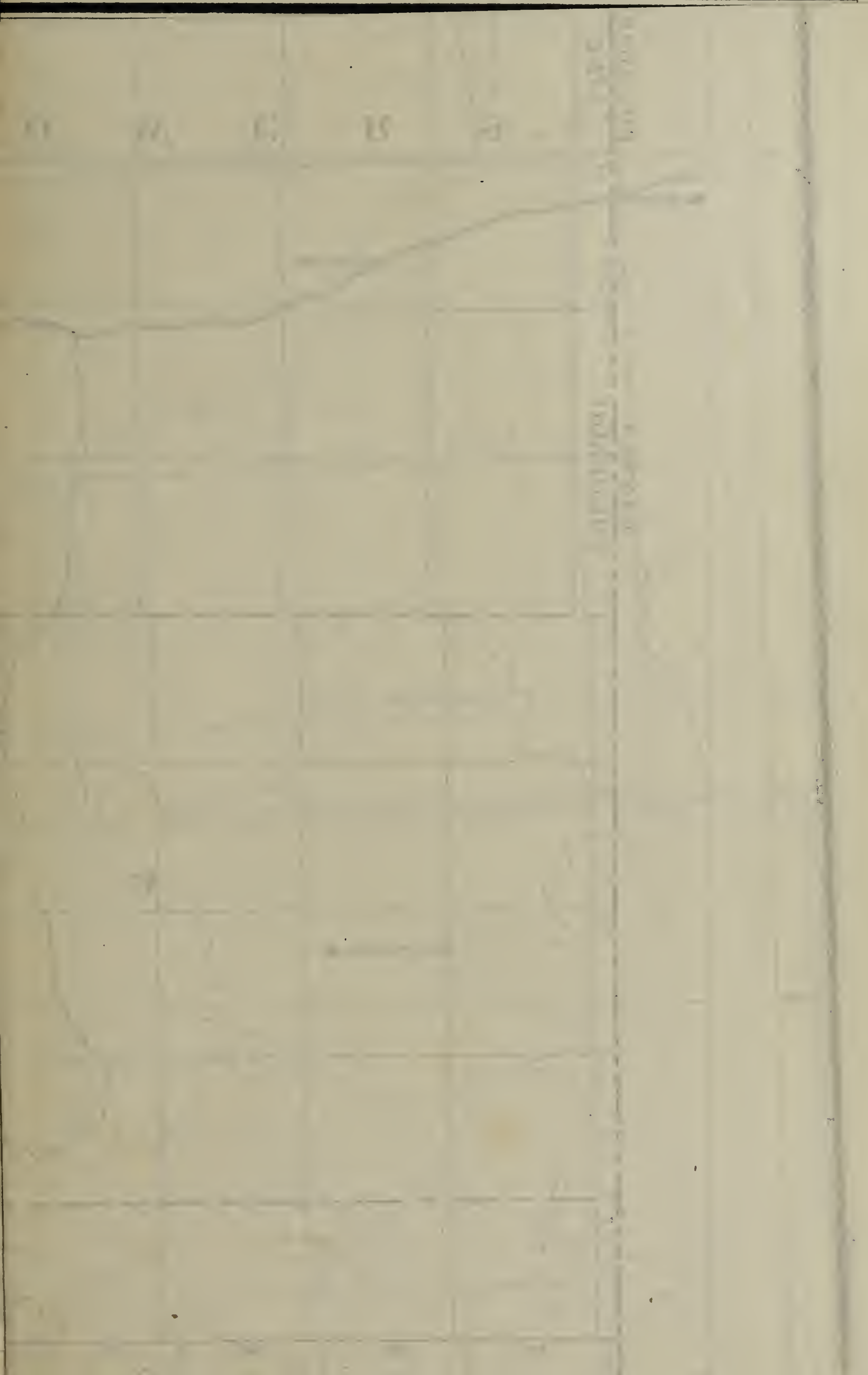
- Wadsworth plains, irrigation of 393
- Wagoner, Luther, cited 301
- Walnut Grove, Arizona 297
- Walnut Grove dam, description of 297–302
  - W. P. Blake on 301
- Walnut Grove reservoir 297–302
- Warm Spring valley 393
- Warren, F. E., cited 140
- Washington State 32, 124, 140, 164
  - drainage basins of 31, 32
- Water, flowing, value of 30
  - date of 155–158
  - application of 274–281
- Water cushions, use of, in India 250
  - construction of, in America 250
  - on Turlock canal 250–251
- Water lifting, use of windmills in 333
  - use of undershot wheels in 333–335
  - use of elevators in 335
- Water storage 284–325
  - growth of popular interest in 286
  - in San Joaquin valley 399–400
- Water supply 1–99
  - subsurface sources of 326–346
  - in San Joaquin valley 405
  - of Salt lake city 458, 459, 460, 461
- Water wheel on Platte River 334
- Water wheels, undershot, use of, for water lifting 333–335
- Water wheels near Blake city 334–335
- Weber river 11, 13, 15
- Weber lake reservoir 392, 397
- Wegmann, Edward, jr., cited 374
- Weir, composite, of Arapaho canal 230
  - crib, Highline canal 224–226
  - Bear river canal 226
  - Kraft district canal 226–227
  - diversion, across San Diego river 230–231
  - at head of Turlock and Modesto canals 231–232
  - masonry 230–234
  - masonry, of Folsom canal 232–234
  - open or flash board 227–230
  - open, Calloway, Del Norte, and Monte Vista canals 227–230
- Weirs 219, 234
  - classification of 219

Page.
Weir ancient native, earlier history of... 220
near Phœnix, Arizona................ 220–221
pile, across Platte river, in Colorado. 221
crib.................................. 221–227
at head of Arizona canal 221–224
Weiser river.........................11, 13, 15, 98, 99
West Carson river..........11. 13. 14, 15, 96, 99, 153
West Gallatin river....................10, 13, 14, 15
Widney, R. M., work of.................. 332
Willow creek, discharge of.............. 372, 378
Wilson, H. M., report of, on engineering work in Colorado, referred to..... 436

Page.
Windmills, use of, for pumping water.... 333
Winningstad, O., work of................ 216
Wooden pipes used in Colorado.......... 339
Works on irrigation, list of.............. 346–349
Wright, C. C., cited....................... 145
Wyoming...................32, 70, 76, 78, 79, 82, 83, 109, 123, 124, 139, 140, 143, 144, 181, 334
Wyoming Development Company's canal. 181–183

Y.

Yellowstone river. 11, 13, 15, 34, 63–73, 93, 98, 153, 164



TOPOGRAPHIC MAP
OF THE
DRAINAGE BASIN OF THE ARKANSAS RIVER
IN COLORADO

SHOWING CATCHMENT AREAS OF RESERVOIR SITES SURVEYED AND
RECOMMENDED FOR SEGREGATION
AND TRIBUTARY CATCHMENT AREAS OF SITES SURVEYED
1891.

Scale: 6 miles - 1 inch

6 5 4 3 2 1 0 6 12 18 24 30 36 Miles

Contour Interval { Below 7000 ft. elevation - 100 ft.
Above " " " - 200 "

UNIVERSITY OF ILLINOIS-URBANA
3 0112 111840796